SCIENTIFIC DIALOGUES,

INTENDED FOR THE

INSTRUCTION AND ENTERTAINMENT

OF

YOUNG PEOPLE:

IN WHICH

THE FIRST PRINCIPLES

OF

NATURAL AND EXPERIMENTAL PHILOSOPHY

ARE FULLY EXPLAINED.

VOL. I. OF MECHANICS.

"Converſation, with the habit of explaining the meaning
"of words, and the ſtructure of common domeſtic imple-
"ments to children, is the ſure and effectual method of
"preparing the mind for the acquirement of ſcience."

EDGEWORTH'S PRACTICAL EDUCATION.

SECOND EDITION, Corrected and Improved.

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1803.

TO THE HONOURABLE

CHARLES BANKS STANHOPE,

AND TO THE HONOURABLE

JAMES HAMILTON STANHOPE.

GENTLEMEN,

I AM defirous of prefixing your names to thefe Volumes in token of the affectionate attachment to which, from me, you are peculiarly entitled. And I am happy in the opportunity which this publication affords me of bringing to your recollection fubjects, in the ftudy of which you fuccefsfully engaged at a very early period of life, and which are of acknowledged importance in the purfuits of every well educated youth.

In perusing this little Work you must bear in your minds, that it is not intended for proficients in philosophical knowledge, but for noviciates in science:—not for yourselves in the present advanced stage of your progress; but for those young persons who are unacquainted with the rudiments of natural and experimental philosophy.

I am too well acquainted with the excellence of your dispositions to suppose it necessary for me to apologize for laying before you a work that has no extraordinary claim to your acceptance. You will I am sure appreciate its value, not so much by its intrinsic contents, as by the good-will with which it is presented.

Before I conclude this short address, permit me to say, that my own happiness will ever be much augmented, by the assurance of the happiness, and distinguished usefulness of those, with whom I have spent so many years of my life, and to whose perma-

nent intereſt, I am ſure, you will acknowledge, I have never been inattentive.

Sincerely wiſhing you, Gentlemen, all the felicity which the honourable exerciſe of diſtinguiſhed talents and virtuous minds can confer upon the poſſeſſors,

I ſubſcribe myſelf

Your very affectionate friend

And obedient Servant,

CLAPTON, May, 1800.

THE AUTHOR.

PREFACE.

THE Author of these little volumes feels himself extremely happy in the opportunity which this publication affords him of acknowledging the obligations he is under to the authors of "Practical Education," for the pleasure and instruction which he has derived from that valuable work. To this he is solely indebted for the idea of writing on the subject of Natural Philosophy for the use of children. How far his plan corresponds with that suggested by Mr. Edgeworth in his chapter on Mechanics, must be left with a candid public to decide.

The Author conceives at least, he shall be justified in asserting, that no introduction to natural and experimental philosophy has been attempted in a method so familiar and easy as that which, in part, he now offers to the public:—none which appears to him so properly adapted to the capacities

of young people of ten or eleven years of age, a period of life, which, from the Author's own experience, he is confident, is by no means too early to induce in children habits of ſcientific reaſoning. In this opinion he is ſanctioned by the authority of Mr. Edgeworth. "Parents," ſays he, "are anxious that children ſhould be converſant with mechanics, and with what "are called the mechanical powers. Certainly no ſpecies of knowledge is better "ſuited to the taſte and capacity of youth, "and yet it ſeldom forms a part of early "inſtruction. Every body talks of the "lever, the wedge, and the pulley, but "moſt people perceive that the notions "which they have of their reſpective uſes "is unſatisfactory and indiſtinct, and many "endeavour, at a late period of life, to ac-"quire a ſcientific and exact knowledge of "the effects that are produced by imple-"ments which are in every body's hands, "or that are abſolutely neceſſary in the "daily occupations of mankind."

Should these volumes be favourably received by the public, the Author proposes to pursue the same plan in four others for which he has ample materials, and which will comprise Optics; Hydrostatics; Pneumatics; Chemistry; Electricity and Magnetism. He is aware that to persons conversant with these subjects, and who are accustomed to the arduous employment of education, hints for the improvement of this work may occur; so far, therefore, from deprecating candid criticism, whether of a public or private nature, he will thankfully attend to every liberal suggestion that may be offered; and will, in the revision of these volumes, or in writing those that remain to the completion of his design, avail himself of every advantage with which he may be favoured.

The Author trusts that the whole work will be found a complete compendium of natural and experimental philosophy, not only adapted to the understandings of young

people, but well calculated alſo to convey that kind of familiar inſtruction which is abſolutely neceſſary, before a perſon can attend public lectures in theſe branches of ſcience with advantage. "If" ſays Mr. Edgeworth, ſpeaking on this ſubject, "the "lecturer does not communicate much of "that knowledge which he endeavours "to explain, it is not to be attributed ei-"ther to his want of ſkill, or to the in-"ſufficiency of his apparatus, but to the "novelty of the terms which he is obliged "to uſe. Ignorance of the language in "which any ſcience is taught, is an in-"ſuperable bar to its being ſuddenly ac-"quired; beſides a preciſe knowledge of "the meaning of terms, we muſt have "an inſtantaneous idea excited in our "minds when ever they are repeated; and, "as this can be acquired only by prac-"tice, it is impoſſible that philoſophical "lectures can be of much ſervice to thoſe "who are not familiarly acquainted with

"the technical language in which they "are delivered *."

It is prefumed that an attentive perufal of thefe dialogues, in which the principal and moft common terms of fcience are carefully explained and illuftrated, by a variety of familiar examples, will be the means of obviating this objection, with refpect to perfons who may be defirous of attending thofe public philofophical lectures, to which the inhabitants of the metropolis have almoft conftant accefs.

* Mr. Edgeworth's chapter on Mechanics fhould be recommended to the attention of the reader, but the Author feels unwilling to refer to part of a work, the whole of which deferves the careful perufal of all perfons engaged in the education of youth.

TO THE BINDER.

Pleafe to place the Plates at the End of the Volumes.

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CONVERSATION I.

INTRODUCTION.

FATHER—CHARLES—EMMA.

CHARLES. Father, you told ſiſter Emma and me, that, after we had finiſhed reading the "*Evenings at Home*," you would explain to us ſome of the principles of natural philoſophy: will you begin this morning?

Father. Yes, I am quite at leiſure; and, I ſhall indeed at all times take a delight in communicating to you the elements of uſeful knowledge;

and the more ſo in proportion to the desire which you have of collecting and ſtoring thoſe facts that may enable you to underſtand the operations of nature, as well as the works of ingenious artists, by which you will, I truſt, be led inſensibly to admire the wiſdom and goodneſs with which the whole ſyſtem of the univerſe is conſtructed and ſupported.

Emma. But can philoſophy be comprehended by children ſo young as we are? I thought that it had been the buſineſs of men, and of old men too.

Father. Philoſophy is a word which in its original ſenſe ſignifies only a love or desire of wisdom; and you will not allow that you and your

brother are too young to wish for knowledge.

Emma. So far from it, that the more knowledge I get, the better I feem to like it; and the number of new ideas which, with a little of your affiftance, I have obtained from the "*Evenings at Home,*" and the great pleafure which I have received from the perufal of thefe volumes, will, I am fure, excite me to read them again and again.

Father. You will find very little in the introductory parts of natural and experimental philofophy, that will require more of your attention than many parts of that work with which you were fo delighted.

Charles. But in fome books of natural philofophy, which I have occafionally looked into, a number of

new and uncommon words have perplexed me; I have alfo feen references to figures by means of large letters and fmall, the ufe of which I did not comprehend.

Father. It is frequently a dangerous practice for young minds to dip into fubjects before they are prepared, by fome previous knowledge, to enter upon them; fince it may create a diftafte for the moft interefting topics. Thus thofe books which you now read with fo much pleafure would not have afforded you the fmalleft entertainment a few years ago, when you muft have fpelt out almoft every word in each page. The fame fort of difguft will naturally be felt by perfons who fhould attempt to read works of fcience before the leading terms are explained and

underftood. The word *angle* is continually recurring in fubjects of this fort, do you know what an angle is?

Emma. I do not think I do; will you explain what it means?

Father. An *angle* is made by the opening of two ftraight* lines. In this figure (Plate 1. Fig. 1.) there are two ftraight lines AB and CB meeting at the point B, and the opening made by them is called an angle.

Charles. Whether that opening be fmall or great, is it ftill called an angle?

Father. It is; your drawing compaffes may familiarize to your mind the idea of an angle; the lines in this figure will aptly reprefent the legs of the compaffes, and the point

* *Straight* lines, in works of fcience, are ufually denominated *right* lines.

at the point upon which they move or turn. Now you may open the legs to any distance you please, even so far that they shall form one straight line, in that position only they do not form an angle. In every other situation an angle is made by the opening of their legs, and the angle is said to be greater or less, as that opening is greater or less.

Emma. Are not some angles called right angles?

Father. Angles are either right, acute, or obtuse. When the line AB (Plate I. Fig. 3.) meets another line CD, in such a manner as to make the angles ABC and ABD equal to one another, then those angles are called right angles. And the line AB is said to be perpendicular to the

Hence to be perpendicular to, or to make *right* angles with a line, means one and the ſame thing.

Charles. Does it ſignify how you call the letters of an angle?

Father. It is uſual to call every angle by three letters, and that at the angular point muſt be always the middle letter of the three. There are caſes, however, where an angle may be denominated by a ſingle letter, as in figures 1 and 3, the angle ABC may be called ſimply the angle B, for in theſe figures there is no danger of miſtake, becauſe there is but a ſingle angle at the point B.

Charles. I underſtand this, for if in the ſecond figure I were to deſcribe the angle by the letter B only, you would not know whether I meant, the angle ABC or ABD.

Father. That is the precife reafon why it is neceffary in moft defcriptions to make ufe of three letters. An *acute* angle (Fig. 1.) ABC is lefs than a right angle; and an *obtufe* angle (Plate 1. Fig. 3.) ABC is greater than a right angle.

Emma. You fee the reafon now, Charles, why letters are placed againft or by the figures, which puzzled you before.

Charles. I do, they are intended to diftinguifh the feparate parts of each, in order to render the defcription of them eafier both to the author and the reader.

Emma. What is the difference, papa, between an angle and a triangle?

Father. An angle being made by the opening of two lines, and, as

you know, that two ſtraight lines cannot encloſe a ſpace, ſo a *triangle* ABC (Plate 1. Fig. 4.) is a ſpace bounded by three ſtraight lines. It takes its name from the property of containing three angles. There are various ſorts of triangles, but it is not neceſſary to enter upon theſe particulars, as I do not wiſh to burden your memories with more technical terms than we have occaſion for.

Charles. A triangle then is a ſpace or figure containing three angles, and bounded by as many ſtraight lines.

Father. Yes, that deſcription will anſwer our preſent purpoſe.

CONVERSATION II.

Of Matter—Of the Divifibility of Matter.

FATHER. Do you underftand what philofophers mean when they make ufe of the word matter?

Emma. Are not all things which we fee and feel compofed of matter?

Father. Every thing which is the object of our fenfes is compofed of matter differently modified or arranged. But in a philofophical fenfe *matter* is defined to be an *extended, folid, inactive,* and *moveable* fubftance.

Charles. If by extenſion is meant length, breadth, and thickneſs, matter, undoubtedly, is an extended ſubſtance. Its ſolidity is manifeſt by the reſiſtance it makes to the touch.

Emma. And the other properties nobody will deny, for all material objects are, of themſelves, without motion; and yet it may be readily conceived, that by the application of a proper force there is no body which cannot be moved. But I remember, papa, that you told us ſomething ſtrange about the diviſibility of matter, which you ſaid might be continued without end.

Father. I did, ſome time back, mention this as a curious and intereſting ſubject, and this is a very fit time for me to explain it.

Charles. Can matter indeed be infinitely divided, for I ſuppoſe that this is what is meant by a diviſion without end?

Father. Difficult as this may at firſt appear, yet I think it very capable of proof. Can you conceive of a particle of matter ſo ſmall as not to have an upper and under ſurface?

Charles. Certainly every portion of matter, however minute, muſt have two ſurfaces at leaſt, and then I ſee, that it follows of courſe that it is diviſible.

Father. Your concluſion is juſt, and though there may be particles of matter too ſmall for us actually to divide, yet this ariſes from the imperfection of our inſtruments; they muſt nevertheleſs, in their nature, be diviſible.

Emma. But you were to give us ſome remarkable inſtances of the minute diviſion of matter.

Father. A few years ago a lady ſpun a ſingle pound of wool into a thread 168 thouſand yards long. And Mr. Boyle mentions that two grains and a half of ſilk was ſpun into a thread 300 yards in length. If a pound of ſilver, which, you know, contains 5760 grains, and a ſingle grain of gold be melted together, the gold will be equally diffuſed through the whole ſilver, inſomuch that if one grain of the maſs be diſſolved in a liquid called *Aqua Fortis,* the gold will fall to the bottom. By this experiment it is evident that a grain may be divided into 5761 viſible parts, for only the 5761ſt part of the gold

is contained in a ſingle grain of the maſs.

The gold-beaters, whom you have ſeen at work in the ſhops in Long-Acre, can ſpread a grain of gold into a leaf containing 50 ſquare inches, and this leaf may be readily divided into 500,000 parts, each of which is viſible to the naked eye: and by the help of a microſcope which magnifies the area or ſurface of a body 100 times, the 100th part of each of theſe becomes viſible, that is the 50 millionth part of a grain of gold will be viſible, or a ſingle grain of that metal may be divided into 50 million of viſible parts. But the gold which covers the ſilver wire uſed in making what is called gold lace, is ſpread over a much larger ſurface, yet it preſerves, even if examined by a mi-

crofcope, an uniform appearance. It has been calculated that one grain of gold under thefe circumftances, would cover a furface of nearly thirty fquare yards.

The *natural* divifions of matter are ftill more furprifing. In odoriferous bodies, fuch as camphor, mufk, and afafœtida, a wonderful fubtilty of parts is perceived, for though they are perpetually filling a confiderable fpace with odoriferous particles, yet thefe bodies lofe but a very fmall part of their weight in a great length of time.

Again, it is faid by thofe who have examined the fubject with the beft glaffes, and whofe accuracy may be relied on, that there are more animals in the milt of a fingle cod-fifh, than there are men on the whole

earth, and that a ſingle grain of ſand is larger than four millions of theſe animals. Now if it be admitted that theſe little animals are poſſeſſed of organiſed parts, ſuch as a heart, ſtomach, muſcles, veins, arteries, &c. and that they are poſſeſſed of a complete ſyſtem of circulating fluids, ſimilar to what is found in larger animals, we ſeem to approach to an idea of the infinite diviſibility of matter. It has indeed been calculated that a particle of the blood of one of theſe animalcula is as much ſmaller than a globe one tenth of an inch in diameter, as that globe is ſmaller than the whole earth. Nevertheleſs, if theſe particles be compared with the particles of light, it is probable, that they would be found to exceed them

in bulk as much as mountains do single grains of sand :

In thousand species of the insect kind !
Lost to the naked eye, so wondrous small
Were millions join'd, one grain of sand would
cover all.
Yet each within its little bulk, contains
An heart which drives the torrent through its
veins :
Muscles to move its limbs aright : a brain
And nerves dispofed for pleasure and for pain :
Eyes to distinguish ; sense whereby to know
What's good, or bad ; is, or is not its foe.

BAKER.

I might enumerate many other instances of the same kind, but these, I doubt not, will be sufficient to convince you into what very minute parts matter is capable of being divided : and with these we will put an end to our present conversation.

CONVERSATION III.

Of the Attraction of Cohesion.

FATHER. Well my children, have you reflected upon what we laſt converſed about? Do you comprehend the ſeveral inſtances which I enumerated as examples of the minute diviſion of matter?

Emma. Indeed, papa, the examples which you gave us very much excited my wonder and admiration, and yet from the thinneſs of ſome leaf gold which I once had, I can readily credit all you have ſaid on that part of the ſubject. But I know not how to conceive of ſuch

ſmall animals as you deſcribed; and I am ſtill more at a loſs how to imagine that animals ſo minute, ſhould poſſeſs all the properties of the larger ones, ſuch as a heart, veins, blood, &c.

Father. I can, the next bright morning, by the help of my ſolar microſcope, ſhew you very diſtinctly, the circulation of the blood in a flea, which you may get from your little dog; and with better glaſſes than thoſe of which I am poſſeſſed, the ſame appearance might be ſeen in animals ſtill ſmaller than the flea, perhaps, even in thoſe which are themſelves inviſible to the naked eye. But we ſhall converſe more at large on this matter, when we come to conſider the ſubject of optics, and the conſtruction and uſes of the ſolar microſcope. At preſent we will turn

our thoughts to that principle in nature, which philoſophers have agreed to call gravity or attraction.

Charles. If there be no more difficulties in philoſophy than we met with in our laſt lecture, I do not fear but that we ſhall, in general, be able to underſtand it. Are there not, papa, ſeveral kinds of gravity?

Father. Yes there are; two of which it will be ſufficient for our preſent purpoſe to deſcribe; the one is the *attraction of coheſion*; the other that of *gravitation.* The *attraction of coheſion* is that power which keeps the parts of bodies together when they touch, and prevents them from ſeparating, or which inclines the parts of bodies to unite, when they are placed ſufficiently near to each other.

Charles. Is it then by the attraction of cohesion that the parts of this table, or of the pen-knife, are kept together?

Father. The instances which you have selected are accurate, but you might have said the same of every other solid substance in the room, and it is in proportion to the different degrees of attraction with which different substances are affected, that some bodies are hard, others soft, tough, &c. A philosopher in Holland, almost a century ago, took great pains in ascertaining the different degrees of cohesion, which belonged to various kinds of wood, metals, and many other substances. A short account of the experiments made by M. Musschenbrock, you will hereafter find in your

own language, in the ſecond edition of Dr. Enfield's Inſtitutes of Natural Philoſophy.

Charles. You once ſhewed me that two leaden bullets having a little ſcraped from the ſurfaces, would ſtick together with great force; you called that, I believe, the attraction of coheſion?

Father. I did: ſome philoſophers, who have made this experiment with great attention and accuracy, aſſert, that if the flat ſurfaces, which are preſented to one another, be but a quarter of an inch in diameter, ſcraped very ſmooth, and forcibly preſſed together with a twiſt, a weight of an hundred pounds is frequently required to ſeparate them.

As it is by this kind of attraction that the parts of ſolid bodies are kept

together, ſo when any ſubſtance is ſeparated or broken, it is only the attraction of coheſion that is overcome in that particular part.

Emma. Then, papa, when I had the misfortune this morning at breakfaſt to let my ſaucer ſlip from my hands, by which it was broken into ſeveral pieces, was it only the attraction of cohesion that was overcome by the parts of the ſaucer being ſeparated by its fall on the ground?

Father. Juſt ſo; for whether you unluckily break the china, or cut a ſtick with your knife, or melt lead over the fire, as your brother ſometimes does, in order to make plummets; theſe and a thouſand other inſtances which are continually occurring, are but examples in which

the cohesion is overcome, by the fall; the knife; or the fire.

Emma. The broken saucer being highly valued by mama, she has taken the pains to join it again with white lead, was this performed by means of the attraction of cohesion?

Father. It was, my dear, and hence you will easily learn that many operations in cookery are in fact nothing more than different methods of causing this attraction to take place. Thus flour, by itself, has little or nothing of this principle, but when mixed with milk, or other liquids, to a proper consistency, the parts cohere strongly, and this cohesion in many instances becomes still stronger, by means of the heat applied to it in boiling or baking.

Charles. You put me in mind, papa, of the fable of the man blowing hot and cold: for in the inſtance of the *lead*, fire overcomes the attraction of coheſion; and the ſame power, heat, when applied to puddings, bread, &c. cauſes their parts to cohere more powerfully. How are we to underſtand this?

Father. I will endeavour to remove your difficulty. Heat expands all bodies without exception, as you ſhall ſee before we have finiſhed our lectures. Now the fire applied to metals in order to melt them, cauſes ſuch an expanſion, that the particles are thrown out of the ſphere, or reach of each other's attraction: whereas the heat communicated in the operations of cookery, is ſufficient to expand the particles of flour,

but is not enough to overcome the attraction of cohesion. Besides your mama will tell you, that the heat of boiling, would frequently disunite the parts of which her puddings are composed, if she did not take the precaution of enclosing them in a cloth, leaving them just room enough to expand without the liberty of breaking to pieces; and the moment they are taken from the water, they lose their superabundant heat, and become solid.

Emma. When Ann the cook makes broth for little brother, it is the heat then which overcomes the attraction which the particles of meat have for each other, for I have seen her pour off the broth, and the meat is all in rags. But will not the heat overcome the attraction which

the parts of the bones have for each other?

Father. The heat of boiling water will never effect this, but a machine was invented feveral years ago, by Mr. Papin, for that purpofe. It is called Papin's digefter, and is ufed in taverns, and in many large families, for the purpofe of diffolving bones, as completely as a leffer degree of heat will liquefy jelly. On fome future day I will fhew you an engraving of this machine, and explain its different parts, which are extremely fimple.*

* See Vol. IV. Conver. XIX. p. 185—8.

CONVERSATION IV.

Of the Attraction of Cohesion.

FATHER. I will now mention ſome other inſtances of this great law of nature. If two poliſhed plates of marble, or braſs, be put together, with a little oil between them to fill up the pores in their ſurfaces, they will cohere ſo powerfully as to require a very conſiderable force to ſeparate them. — Two globules of quickſilver placed very near to each other, will run together and form one large drop.—Drops of water will do the ſame.—Two circular pieces of cork placed upon water at about an

inch diſtant will run together.—Balance a piece of ſmooth board on the end of a ſcale beam; then let it lie flat on water, and five or ſix times its own weight will be required to ſeparate it from the water. If a ſmall globule of quickſilver be laid on clean paper, and a piece of glaſs be brought into contact with it, the mercury will adhere to it, and be drawn away from the paper. But bring a larger globule into contact with the ſmaller one, and it will forſake the glaſs, and unite with the other quickſilver.

Charles. Did not you tell me that it was by means of the attraction of coheſion, that the little tea which is generally left at the bottom of the cup inſtantly aſcends in the ſugar when thrown into it?

Father. The afcent of water or other liquids in fugar, fponge, and all porous bodies is a fpecies of this attraction, and is called *capillary** *attraction;* it is thus denominated from the property which tubes of a very fmall bore, fcarcely larger than to admit a hair, have of caufing water to ftand above its level.

Charles. Is this property vifible in no other tubes than thofe, the bores of which are fo exceedingly fine?

Father. Yes, it is very apparent in tubes whofe diameters are one tenth of an inch or more in length, but the fmaller the bore, the higher the fluid rifes; for it afcends, in all inftances, till the weight of the co-

* From *capillus*, the latin word for *hair*.

lumn of water in the tube balances, or is equal to the attraction of the tube. By immerſing tubes of different bores in a veſſel of coloured water, you will ſee that the water riſes as much higher in the ſmaller tube, than in the larger, as its bore is leſs than that of the larger. The water will riſe a quarter of an inch, and there remain ſuſpended in a tube, whoſe bore is about one eighth of an inch in diameter.

This kind of attraction is well illuſtrated, by taking (Plate I. Fig. 5.) two pieces of glaſs joined together at the ſide BC, and kept a little open at the oppoſite ſide AD, by a ſmall piece of cork E. In this poſition immerſe them in a diſh of coloured water FG, and you will obſerve that the attraction of the glaſs at, and near BC, will

caufe the fluid to afcend to B, whereas about the parts D, it fcarcely rifes above the level of the water in the veffel.

Charles. I fee that a curve is formed by the water.

Father. There is, and to this curve there are many curious properties belonging, as you will hereafter be able to inveftigate for yourfelf.

Emma. Is it not upon the principle of the attraction of cohefion, that carpenters glue their work together?

Father. It is upon this principle that carpenters and cabinet-makers make ufe of glue; that braziers, tinmen, plumbers, &c. folder their metals; and that fmiths unite different bars of iron by means of heat. Thefe and a thoufand other operations, of

which we are continually the witnesses, depend on the same principle as that which induced your mama to use the white lead in mending her saucer. And you ought to be told, that though white lead is frequently used as a cement for broken china, glass and earthen ware, yet if the vessels are to be brought again into use, it is not a proper cement, being an active poison; besides one much stronger has been discovered, I believe, by a very able and ingenious philosopher, the late Dr. Ingenhouz, at least I had it from him several years ago; it consists simply of a mixture of quick-lime, and Glocester cheese, rendered soft by warm water, and worked up to a proper consistency.

Emma. What! do such great philosophers, as I have heard you say

Dr. Ingenhouz was, attend to ſuch trifling things as theſe?

Father. He was a man deeply ſkilled in many branches of ſcience; and I hope that you and your brother will one day make yourſelves acquainted with many of his important diſcoveries. But no real philoſopher will conſider it beneath his attention to add to the conveniencies of life.

Charles. This attraction of coheſion ſeems to pervade the whole of nature.

Father. It does, but you will not forget that it acts only at very ſmall diſtances. Some bodies indeed appear to poſſeſs a power the reverſe of the attraction of coheſion.

Emma. What is that, Papa?

Father. It is called repulſion.

Thus water repels moft bodies till they are wet. A fmall needle carefully placed on water will fwim: flies walk upon it without wetting their feet:

> Or b[illegible] unwet their oily forms, and dwell
> With feet repulfive on the dimpling well.
>
> DARWIN.

The drops of dew which appear in a morning on plants, particularly on cabbage plants, affume a globular form, from the mutual attraction between the particles of water; and upon examination it will be found that the drops do not touch the leaves, for they will roll off in compact bodies, which could not be the cafe if there fubfifted any degree of attraction between the water and the leaf.

If a fmall thin piece of iron be laid upon quickfilver, the repulfion

between the different metals will caufe the furface of the quickfilver near the iron to be depreffed.

The repelling force of the particles of a fluid is but fmall; therefore, if a fluid be divided it eafily unites again. But if a glafs or any hard fubftance be broken, the parts cannot be made to cohere without being firft moiftened, becaufe the repulfion is too great to admit of a reunion.

The repelling force between water and oil is likewife fo great, that it is almoft impoffible to mix them in fuch a manner, that they fhall not feparate again.

If a ball of light wood be dipt in oil, and then put into water, the water will recede fo as to form a fmall channel around the ball.

Charles. Why do cane, ſteel, and many other things bear to be bent without breaking, and, when ſet at liberty again, recover their original form?

Father. That a piece of thin ſteel, or cane, recovers its uſual form after being bent, is owing to a certain power, called *elaſticity*; which may, perhaps, ariſe from the particles of thoſe bodies, though diſturbed, not being drawn out of each other's attraction; therefore, as ſoon as the force upon them ceaſes to act, they reſtore themſelves to their former poſition.—But our half hour is expired, I muſt leave you.

CONVERSATION V.

Of the Attraction of Gravitation.

FATHER. We will now proceed to discuss another very important general principle in nature; the *attraction of gravitation*, or as it is frequently termed *gravity*, which is that power by which *distant* bodies tend towards each other. Of this we have perpetual instances in the falling of bodies to the earth.

Charles. Am I then to understand, that whether this marble falls from my hand; or a loose brick from the top of the house; or an

apple from the tree in the orchard, that all thefe happen by the attraction of gravity?

Father. It is by the power which is commonly expreffed under the term *gravity*, that all bodies whatever have a tendency to the earth, and, unlefs fupported, will fall in lines nearly perpendicular to its furface.

Emma. But are not fmoak, fteam, and other light bodies which we fee afcend, exceptions to the general rule?

Father. It appears fo at firft fight, and it was formerly received as a general opinion, that fmoke, fteam, &c. poffeffed no weight: the difcovery of the air-pump has fhewn the fallacy of this notion, for in an exhaufted receiver, that is, in a glafs jar

from which the air is taken away by means of the air-pump, ſmoke and ſteam deſcend by their own weight as completely as a piece of lead. When we come to converſe on the ſubjects of pneumatics and hydroſtatics, you will underſtand that the reaſon why ſmoke, and other bodies aſcend, is ſimply becauſe they are lighter than the atmoſphere which ſurrounds them, and the moment they reach that part of it which has the ſame gravity with themſelves they ceaſe to riſe.

Charles. Is it then by this power that all terreſtrial bodies remain firm on the earth?

Father. By gravity, bodies on all parts of the earth (which you know is of a globular form) are kept on its ſurface, becauſe they all, wherever

ſituated, tend to the center; and, ſince all have a tendency to the center, the inhabitants of New Zealand, although nearly oppoſite to our feet, ſtand as firm as we do in Great Britain.

Charles. This is difficult to comprehend, nevertheleſs, if bodies on all parts of the ſurface of the earth have a tendency to the center, there ſeems no reaſon why bodies ſhould not ſtand as firm on one part as well as another. Does this power of gravity act alike on all bodies?

Father. It does, without any regard to their figure, or ſize; for attraction or gravity acts upon bodies in proportion to the quantity of matter which they contain, that is, four times a greater force of gravity is exerted upon a weight of four pounds,

than upon one of a fingle pound. The confequence of this principle is, that all bodies at equal diftances from the earth fall with equal velocity.

Emma. What do you mean, Papa, by *velocity?*

Father. I will explain it by an example or two; if you and Charles fet out together, and *you* walk a mile in half an hour, but *he* walks and run two miles in the fame time, how much fwifter will he go than you?

Emma. Twice as fwift.

Father. He does, becaufe *in the fame time,* he paffes over twice as much fpace; therefore we fay his velocity is twice as great as your's. Suppofe a ball, fired from a cannon, pafs through 800. feet in a fecond of time; and in the fame time your

brother's arrow paſs through 100 feet only, how much ſwifter does the cannon ball fly than the arrow?

Emma. Eight times ſwifter.

Father. Then it has eight times the velocity of the arrow; and hence you underſtand that ſwiftneſs and velocity are ſynonymous terms; and that the velocity of a body is meaſured by the ſpace it paſſes over in a given time, as a ſecond, a minute, an hour, &c.

Emma. If I let a piece of metal, as a penny piece, and a feather fall from my hand at the ſame time, the penny will reach the ground much ſooner than the feather. Now how do you account for this if all bodies are equally affected by gravitation, and deſcend with equal velocities,

when at the ſame diſtance from the earth?

Father. Though the penny and feather will not in the open air, fall with equal velocity, yet if the air be taken away, which is eaſily done, by a little apparatus connected with the air-pump, they will deſcend in the ſame time. Therefore the true reaſon why light and heavy bodies do not fall with equal velocities, is, that the *former*, in proportion to its weight, meets with a much greater reſiſtance from the air than the *latter*.

Charles. It is then, I imagine, from the ſame cauſe that if I drop the penny and a piece of light wood into a veſſel of water, the penny ſhall reach the bottom, but the

wood, after defcending a fmall way, rifes to the furface.

Father. In this cafe the refifting medium is water inftead of air, and the copper, being about nine times heavier than its bulk of water, falls to the bottom without apparent refiftance. But the wood, being much lighter than water, cannot fink in it, therefore, though by its *momentum**, it finks a fmall diftance, yet as foon as that is overcome by the refifting medium, it rifes to the furface, being the lighter fubftance.

* The explanation of this term will be found in the next converfation.

CONVERSATION VI.

Of the Attraction of Gravitation.

EMMA. The term *momentum* which you made uſe of yeſterday, is another word which I do not underſtand.

Father. If you have underſtood what I have ſaid reſpecting the velocity of moving bodies, you will eaſily comprehend what is meant by the word momentum.

The *momentum* or moving force of a body, is its weight multiplied into its velocity. You may, for inſtance, place this pound weight upon a china

plate without any danger of breaking, but if you let it fall from the height of only a few inches it will dafh the china to pieces. In the firft cafe, the plate has only the pound weight to fuftain, in the other, the weight muft be multiplied into the velocity, or, to fpeak in a popular manner, into the diftance of the height from which it fell.

If a ball *a* (Plate 1. Fig. 6.) lean against the obftacle *b*, it will not be able to overturn it, but if it be taken up to *c* and fuffered to roll down the inclined plane AB againft *b* it will certainly overthrow it;—in the former cafe, *b* would only have to refift the weight of the ball *a*, in the latter it has to refift the weight multiplied into its motion, or velocity.

Charles. Then the momentum of a fmall body, whofe velocity is very great, may be equal to that of a very large body with a flow velocity.

Father. It may, and hence you fee the reafon why immenfe battering rams, ufed by the ancients, in the art of war, have given place to cannon balls of but a few pounds weight.

Charles. I do, for what is wanting in weight, is made up by velocity.

Father. Can you tell me what velocity a cannon ball of 28 pounds muft have, to effect the fame purpofes, as would be produced by a battering ram of 15,000 pounds weight, and which by manual ftrength, could be moved at the rate of only two feet in a fecond of time?

Charles. I think I can;—the *momentum* of the battering ram muſt be eſtimated by its weight, multiplied into the ſpace paſſed over in a ſecond, which is 15,000 multiplied by two feet equal to 30,000; now if this momentum, which muſt alſo be that of the cannon ball, be divided by the weight of the ball, it will give the velocity required; and 30,000 divided by 28, will give for the quotient 1072 nearly, which is the number of feet which the cannon ball muſt paſs over in a ſecond, in order that the momenta of the battering ram and the ball may be equal, or in other words, that they may have the ſame effect in beating down an enemy's wall.

Emma. I now fully comprehend what the momentum of a body is,

for if I let a common trap-ball accidentally fall from my hand, upon my foot, it occaſions more pain than the mere preſſure of a weight ſeveral times heavier.

Father. If you let a pound, or a hundred pounds fall on the floor, only from the height of an inch and a quarter, it will ſtrike the floor with a momentum equal to double its weight: and if you let it fall from four times that height, or five inches, it will have double that effect;—and if it fall nine times that height, or eleven inches and a quarter, it will have treble the effect;—and by falling ſixteen times the height, or twenty inches, it will have four times the effect, and ſo on. Hence it is plain, that if you let the ball drop from your hand at the height of twenty

inches only, it will have eight times more effect in caufing pain than the mere preffure of the ball itfelf.

Charles. If the attraction of gravitation be a power by which bodies in general tend towards each other, why do all bodies tend to the earth as a center?

Father. I have already told you that by the great law of gravitation, the attraction of all bodies is in proportion to the quantity of matter which they contain. Now the earth, being fo immenfely large in comparifon of all other fubftances in its vicinity, deftroys the effect of this attraction between fmaller bodies, by bringing them all to itfelf.—If two balls are let fall from a high tower at a fmall diftance apart; though they have an attraction for one ano-

ther, yet it will be as nothing when compared with the attraction by which they are both impelled to the earth, and consequently the tendency which they mutually have of approaching one another will not be perceived in the fall. If, however, any two bodies were placed in free space, and out of the sphere of the earth's attraction, they would, in that case, assuredly fall toward each other, and that with increased velocity as they came nearer. If the bodies were equal, they would meet in the middle point between the two; but if they were unequal, they would then meet as much nearer the larger one, as that contained a greater quantity of matter than the other.

Charles. According to this, the earth ought to move towards falling

bodies, as well as they move to it.

Father. It ought, and, in juſt theory, it does, but when you calculate how many million of times larger the earth is than any thing belonging to it: and if you reckon the ſmall diſtances from which bodies can fall, you will then know that the point where the falling bodies and earth will meet, is removed only to an indefinitely ſmall diſtance from its ſurface, a diſtance much too ſmall to be conceived by the human imagination.

We will reſume the ſubject of gravity to-morrow.

CONVERSATION VII.

Of the Attraction of Gravitation.

EMMA. Has the attraction of gravitation, papa, the ſame effect on all bodies, whatever be their diſtance from the earth?

Father. No; this, like every power which proceeds from a center, decreaſes as the ſquares of the diſtances from that center increase.

Emma. I fear that I ſhall not underſtand this unleſs you illuſtrate it by examples.

Father. Suppoſe you are reading at the diſtance of one foot from a

candle, and that you receive a certain quantity of light on your book; now if you remove to the diſtance of two feet from the candle, you will, by this law, enjoy four times leſs light than you had before; here then though you have increaſed your diſtance but two-fold, yet the light is diminiſhed four-fold, becauſe four is the ſquare of two, or two multiplied by itſelf. If inſtead of removing two feet from the candle, you take your ſtation at 3, 4, 5, or 6 feet diſtance, you will then receive at the different diſtances, 9, 16, 25, 36 times leſs light than when you were within a ſingle foot from the candle, for theſe, as you know, are the ſquares of the numbers, 3, 4, 5 and 6. The ſame is applicable to the heat imparted by a fire; at the diſtance of

one yard from which, a perſon will enjoy four times as much heat, as he who ſits or ſtands two yards from it; and nine times as much as one that ſhall be removed to the diſtance of three yards.

Charles. Is then the attraction of gravity four times leſs at a yard diſtance from the earth, than it is at the ſurface?

Father. No; whatever be the cauſe of attraction, which to this day remains undiſcovered, it acts from the *center* of the earth, and not from its ſurface, and hence the difference of the power of gravity cannot be diſcerned at the ſmall diſtances to which we can have acceſs; for a mile or two, which is much higher than, in general, we have opportunites of making experiments, is

nothing in comparison of 4000 miles, the diſtance of the center from the ſurface of the earth. But could we aſcend 4000 miles above the earth, and of courſe be double the diſtance that we now are from the center, we ſhould there find that the attractive force would be but one fourth of what it is here; or in other words that a body, which, at the ſurface of the earth, weighs one pound, and, by the force of gravity, falls through ſixteen feet in a ſecond of time, would at 4000 miles above the earth weigh but a quarter of a pound, and fall through only four feet in a ſecond.*

* Ex. Suppoſe it were required to find the weight of a leaden ball, at the top of a mountain three miles high, which, on the ſurface of the earth weighs 20lb.

If the ſemi-diameter of the earth be taken at 4000; then add to this the height of the

Emma. How is that known, papa, for nobody ever was there?

Father. You are right, my dear, for Garnerin, who laſt ſummer aſtoniſhed all the people of the metropolis and its neighbourhood, by his flight in a balloon, aſcended but a little way in compariſon of the diſtance that we are ſpeaking of. However I will try to explain in what manner philoſophers have come by their knowledge on this ſubject.

The moon is a heavy body connected with the earth by this bond of attraction, and by the moſt accurate

mountain, and ſay as the ſquare of 4003 is to the ſquare of 4000, ſo is 20lb. to a fourth proportional: or as 16024009 : 16000000 : 20 : 19.97 or ſomething more than 19lb. 15½oz, which is the weight of the leaden ball at the top of the mountain.

observations, it is known to be obedient to the ſame laws as other heavy bodies are: its diſtance is alſo clearly aſcertained, being about 240,000 miles, or equal to about ſixty ſemi-diameters of the earth, and of courſe the earth's attraction upon the moon ought to diminiſh in the proportion of the ſquare of this diſtance, that is, it ought to be 60 times 60, or 3600 times leſs at the moon than it is at the ſurface of the earth. This is found to be the caſe.

Again, the earth is not a perfect ſphere, but a ſpheroid, that is of the ſhape of an orange, rather flat at the two ends called the poles, and the diſtance from the centre to the poles is about ſeventeen or eighteen miles leſs than its diſtance from the center to the equator, conſequently, bodies

ought to be ſomething heavier at, and near the poles, than they are at the equator, which is alſo found to be the caſe. Hence it is inferred that the attraction of gravitation varies at all diſtances from the center of the earth, in proportion as the ſquares of thoſe diſtances increaſe.

Charles. It ſeems very ſurpriſing that philoſophers who have diſcovered ſo many things, have not been able to find out the cauſe of gravity. Had Sir Iſaac Newton been aſked why a marble, dropped from the hand, falls to the ground, could he not have aſſigned the reaſon?

Father. That great man, probably the greateſt man that ever adorned this world, was as modeſt as he was great, and he would have told you he knew not the cauſe.

The excellent and learned Dr. Price, in a work which he publifhed eighteen years ago, afks, "who does not remember a time when he would have wondered at the queftion, *why does water run down hill?* What ignorant man is there who is not perfuaded that he underftands this perfectly? But every *improved* man knows it to be a queftion he cannot anfwer." For the defcent of water, like that of other heavy bodies, depends upon the attraction of gravitation, the caufe of which is ftill involved in darknefs.

Emma. You juft now faid that heavy bodies by the force of gravity fall fixteen feet in a fecond of time, is that always the cafe?

Father. Yes, all bodies near the furface of the earth fall at that rate

in the firſt ſecond of time, but as the attraction of gravitation is continually acting; ſo the velocity of falling bodies is an increaſing, or as it is uſually called, an *accelerating* velocity. It is found by very accurate experiments, that a body, deſcending from a conſiderable height by the force of gravity, falls 16 feet in the firſt ſecond of time; 3 times 16 feet in the next; 5 times 16 feet in the third; 7 times 16 feet in the fourth ſecond of time; and ſo on, continually increaſing according to the odd numbers, 1, 3, 5, 7, 9, 11, &c.

CONVERSATION VIII.

Of the Attraction of Gravitation.

EMMA. And would a ball of twenty pounds weight here, weigh half an ounce lefs on the top of the mountain?

Father. Certainly: but you would not be able to afcertain it by means of a pair of fcales and another weight, becaufe both weights being in fimilar fituations would lofe equal portions of their gravity.

Emma. How, then, would you make the experiment?

Father. By means of one of thofe

steel ſpiral-ſpring inſtruments which you have ſeen occaſionally uſed, the fact might be aſcertained.

Charles. I think, from what you told us yeſterday, that with the aſſiſtance of your ſtop watch, I could tell the height of any place, by obſerving the number of ſeconds, that a marble or other heavy body would take in falling from that height.

Father. How would you perform the calculation?

Charles. I ſhould go through the multiplications according to the number of ſeconds, and then add them together.

Father. Explain yourſelf more particularly;—ſuppoſing you were to let a marble or penny-piece fall down that deep well which we ſaw laſt ſummer in the brick field near

Ramsgate, and that it was exactly five seconds in the descent, what would be the depth of the well?

Charles. In the first second it would fall 16 feet; in the next 3 times 16 or 48 feet; in the third 5 times 16 or 80 feet; in the fourth 7 times 16 or 112 feet; and in the fifth second 9 times 16 or 144 feet: now if I add 16, 48, 80, 112, and 144 together, the sum will be 400 feet, which according to your rule is the depth of the well. But was the well so deep?

Father. I do not think it was, but we did not make the experiment; should we ever go to that place again, you may satisfy your curiosity. You recollect that at Dover Castle we were told of a well there 360 feet deep.

Though your calculation was ac-

curate, yet it was not done as nature effects her operations, it was not performed in the shortest way.

Charles. I should be pleased to know an easier method; this however is very simple, it required nothing but multiplication and addition.

Father. True, but suppose I had given you an example in which the number of seconds had been fifty instead of five, the work would have taken you an hour or more to have performed: whereas, by the rule which I am going to give, it might have been done in half a minute.

Charles. Pray let me have it, papa, I hope it will be easily remembered.

Father. It will; I think it cannot be forgotten after it is once un-

derſtood. The rule is this, "*the ſpaces deſcribed by a body falling freely from a ſtate of reſt, increaſe as the* SQUARES *of the times encreaſe.*" Conſequently you have only to ſquare the number of ſeconds, that is, you know, to multiply the number into itſelf; and then multiply that again by ſixteen feet, the ſpace which it deſcribes in the firſt ſecond, and you have the required anſwer. Now try the example of the *well.*

Charles. The ſquare of 5, for the time, is 25, which multiplied by 16 gives 400, juſt as I brought it out before. Now if the ſeconds had been 50, the anſwer would be 50 times 50, which is 2500, and this multiplied by 16, gives 40,000 for the ſpace required.

Father. I will now aſk your ſiſter

a queſtion to try how ſhe has underſtood this ſubject. Suppoſe you obſerve by this watch that the time of the flight of your brother's arrow is exactly ſix ſeconds, to what height does it riſe?

Emma. This is a different queſtion, becauſe here the *aſcent* as well as the *fall* of the arrow is to be conſidered.

Father. But you will remember, that the time of the aſcent is always equal to that of the deſcent; for as the velocity of the deſcent is generated by the force of gravity, ſo is the velocity of the aſcent deſtroyed by the ſame force.

Emma. Then the arrow was three ſeconds only in falling; now the ſquare of 3 is 9, which multiplied by 16, for the number of feet deſcribed

in the firſt ſecond, is equal to 144 feet the height to which it roſe.

Father. Now, Charles, if I get you a bow which will carry an arrow ſo high as to be fourteen ſeconds in its flight, can you tell me the height to which it aſcends?

Charles. I can now anſwer you without heſitation;—it will be 7 ſeconds in falling, the ſquare of which is 49, and this again multiplied by 16 will give 784 feet, or rather more than 261 yards for the anſwer.

Father. If you will now conſider the example which you did the long way, you will ſee that the rule which I have given you anſwers very completely. In the firſt ſecond the body fell 16 feet, and in the next 48, theſe added together make 64, which is the ſquare of the 2 ſeconds multi-

plied by 16. The fame holds true of the 3 firft feconds, for in the third fecond it fell 80 feet, which added to the 64, give 144 equal to the fquare of 3 multiplied by 16. Again, in the fourth fecond it fell 112 feet, which added to 144, give 256 equal to the fquare of 4 multiplied by 16: and in the fifth fecond it fell 144 feet, which added to 256, give 400 equal to the fquare of 5 multiplied by 16. Thus you will find, the rule holds in all cafes, *that the fpaces defcribed by bodies falling freely from a ftate of reft, increafe as the* SQUARES *of the times increafe.*

Charles. I think I fhall not forget the rule. I will alfo fhew my coufin Henry how he may know the height to which his bow will carry.

Father. The fureft way of keep-

ing what knowledge we have obtained, is by communicating it to our friends.

Charles. It is a very pleafant circumftance indeed, that the giving away is the beft method of keeping, for I am fure, the being able to oblige one's friends is a moft delightful thing.

Father. I have but a word or two more on the fubject:—fince the *whole fpaces* defcribed increafe as the fquares of the times increafe, fo alfo the *velocities* of falling bodies increafe in the fame proportion; for you know that the velocity muft be meafured by the fpace paffed through. Thus if a perfon travels fix miles an hour, and another perfon travels twelve miles in the fame time, the latter will go with double the velocity

of the former; confequently the *velocities* of falling bodies increafe as the fquares of the times increafe.

If now you compare the fpaces defcribed by falling bodies in the *feveral moments of time taken feparately*, and in their order from the beginning of the fall, then they, and confequently their velocities alfo, are to one another as the odd numbers, 1, 3, 5, 7, 9, 11, 13, &c. taken in their natural order, as you will obferve by reflecting on the foregoing examples.

With this we conclude our prefent converfation.

CONVERSATION IX.

On the Center of Gravity.

FATHER. We are now going to treat upon the *Center of Gravity*, which is that point of a body, in which its whole weight is as it were concentrated, and upon which if the body be freely ſuſpended it will reſt; and in all other poſitions it will endeavour to deſcend to the loweſt place to which it can get.

Charles. All bodies then, of whatever ſhape, have a centre of gravity?

Father. They have: and if you conceive a line drawn from the center of gravity of a body towards the center of the earth, that line is called the *line of direction*, along which every body, not ſupported, endeavours to fall. If the *line of direction* fall within the baſe of any body, it will ſtand; but if it does not fall within the baſe, the body will fall.

If I place the piece of wood A (Plate I, Fig. 7.) on the edge of a table, and from a pin *a* at its center of gravity be hung a little weight *b*, the line of direction *ab* falls within the baſe, and therefore, though the wood leans, yet it ſtands ſecure. But if upon A, another piece of wood B be placed, it is evident that the center of gravity of the whole will be now raiſed to *c*, at which point if a

weight be hung, it will be found that the line of direction falls out of the base, and therefore the body must fall.

Emma. I think, I now see the reason of the advice which you gave me, when we were going across the Thames in a boat.

Father. I told you that if ever you were overtaken by a storm, or by a squall of wind while you were on the water, never to let your fears so get the better of you, as to make you rise from your seat, because by so doing you would elevate the center of gravity, and thereby, as is evident by the last experiment, increase the danger: whereas if all the persons in the vessel, were, at the moment of danger, instantly to slip from their places on to the bottom,

the riſque would be exceedingly diminiſhed, by bringing the center of gravity much lower within the veſſel. The ſame principle is applicable to thoſe who may be in danger of being overturned in any carriage whatever.

Emma. Surely then, papa, thoſe ſtages which load their tops with a dozen or more people, cannot be ſafe for the paſſengers.

Father. They are very unſafe, but they would be more ſo, were not the roads about the metropolis remarkably even and good; and, in general, it is only within twenty or thirty miles of London, or other great towns, that the tops of carriages are loaded to exceſs.

Charles. I underſtand then, that the nearer the center of gravity is

to the baſe of a body, the firmer it will ſtand.

Father. Certainly, and hence you learn the reaſon why conical bodies ſtand ſo ſure on their baſes, for the tops being ſmall in compariſon of the lower parts, the center of gravity is thrown very low: and if the cone be upright or perpendicular, the line of direction falls in the middle of the baſe, which is another fundamental property of ſteadineſs in bodies. For the broader the baſe, and the nearer the line of direction is to the middle of it, the more firmly does a body ſtand: but if the line of direction fall near the edge the body is eaſily overthrown.

Charles. Is that the reaſon why a ball is ſo eaſily rolled along a horizontal plane?

Father. It is; for in all spherical bodies, the base is but a point, consequently almost the smallest force is sufficient to remove the line of direction out of it. Hence it is evident, that heavy bodies situated on an inclined plane will, while the line of direction falls within the base, slide down upon the plane: but they will roll when that line falls without the base. The body A (Plate 1, Fig. 8.) will slide down the plane DE, but the bodies B and C will roll down it.

Emma. I have seen buildings lean very much out of a straight line, why do they not fall?

Father. It does not follow, because a building leans, that the center of gravity does not fall within the base. There is a high tower at Pisa, a town in Italy, which leans fifteen

feet out of the perpendicular; ſtrangers tremble to paſs by it, ſtill it is found by experiment that the line of direction falls within the baſe, and therefore it will ſtand while its materials hold together.

A wall at Bridgenorth in Shropſhire, which I have ſeen, ſtands in a ſimilar ſituation, for ſo long as a line *cb* (Plate II. Fig. 9.) let fall from the center of gravity *c* of the building AB, paſſes within the baſe CB, it will remain firm, unleſs the materials with which it is built go to decay.

Charles. It muſt be of great uſe in many caſes to know the method of finding the center of gravity in different kinds of bodies.

Father. There are many eaſy rules for this with reſpect to all manageable bodies: I will mention one,

which depends on the property which the center of gravity has, of always endeavouring to defcend to the loweft point.

If a body A (Plate II. Fig. 10.) be freely fufpended on a pin *a*, and a plumb line *a* B be hung by the fame pin, it will pafs through the center of gravity, for that center is not in the loweft point, till it fall in the fame line as the plumb line. Mark the line *a* B; then hang the body up by any other point, as D, with the plumb line DE, which will alfo pafs through the center of gravity for the fame reafon as before: and therefore as the center of gravity is fomewhere in *a* B, and alfo in fome point of DE, it muft be in the point C where thofe lines crofs.

CONVERSATION X.

Of the Center of Gravity.

CHARLES. How do thofe people who have to load carts and waggons with light goods, as hay, wool, &c. know where to find the center of gravity?

Father. Perhaps the generality of them never heard of fuch a principle; and it feems furprifing that they fhould neverthelefs make up their loads with fuch accuracy as to keep the line of direction, in or near the middle of the bafe.

Emma. I have fometimes trembled to pafs by the hop-waggons

which we have met on the Kent road.

Father. And without any impeachment of your courage, for they are loaded to ſuch an enormous height, that they totter every inch of the road. It would indeed be impoſſible for one of theſe to paſs with tolerable ſecurity along a road much inclined, the center of gravity being removed ſo high above the body of the carriage, a ſmall declination on one ſide or the other would throw the line of direction out of the baſe.

Emma. When brother James falls about, is it becauſe he cannot keep the center of gravity between his feet?

Father. That is the preciſe reaſon why any perſon, whether old or

young, falls. And hence you learn that a man ſtands much firmer with his feet a little apart than if they were quite cloſe, for by ſeparating them he increaſes the baſe. Hence alſo the difficulty of ſuſtaining a tall body, as a walking cane, upon a narrow foundation.

Emma. How do rope and wire dancers, whom I have ſeen at the Circus, manage to balance themſelves?

Father. They generally hold a long pole, with weights at each end, acroſs the rope on which they dance, keeping their eyes fixed on ſome object parallel to the rope, by which means they know when their center of gravity declines to one ſide of the rope or the other, and thus by the help of the pole, they are enabled to

keep the center of gravity over the baſe, narrow as it is. It is not however rope-dancers only, who pay attention to this principle, but the moſt common actions of the people in general, are regulated by it.

Charles. In what reſpects?

Father. We bend forward, when we go up ſtairs, or riſe from our chair, for when we are ſitting, our center of gravity is on the ſeat, and the line of direction falls behind our baſe; we therefore lean forwards to bring the line of direction towards our feet. For the ſame reaſon a man carrying a burden on his back leans forward: and backward if he carries it on his breaſt. If the load be placed on one ſhoulder he leans to the other. If we ſlip or ſtumble with one foot, we naturally extend

the oppoſite arm, making the ſame uſe of it as the rope-dancer does of his pole.

This property of the center of gravity always endeavouring to deſcend, will account for appearances, which are ſometimes exhibited to excite the ſurpriſe of ſpectators.

Emma. What are thoſe, papa?

Father. One is, that of a double cone, appearing to roll up two inclined planes, forming an angle with each other, for as it rolls it ſinks between them, and by that means the center of gravity is actually deſcending.

Let a body EF (Plate II. Fig. 13.) conſiſting of two equal cones united at their baſes, be placed upon the edges of two ſtraight ſmooth rulers, AB and CD, which at one end meet

in an angle at A, and reſt on an horizontal plane; and at the other are raiſed a little above the plane; the body will roll towards the elevated end of the rulers, and appear to aſcend; the parts of the cone that reſt on the rulers growing ſmaller as they go over a larger opening, and thus letting it down, the center of gravity deſcends. But you muſt remember that the height of the planes muſt be leſs than the radius of the baſe of the cone.

Charles. Is it upon this principle that a cylinder is made to roll up hill?

Father. Yes it is, but this can be effected only to a ſmall diſtance. If a cylinder of paſte-board, or very light wood AB, (Plate II. Fig. 11.) having its center of gravity at C, be

placed on the inclined plane CD, it will roll down the inclined plane, because a line of direction from that center lies out of the base. If I now fill the little hole *o* with a plug of lead, it will roll up the inclined plane, till the lead gets near the base, where it will lie still: because the center of gravity by means of the lead is removed from *c* towards the plug, and therefore is descending, though the cylinder is ascending.

Before I put an end to this subject, I will shew you another experiment, which without understanding the principle of the center of gravity cannot be explained. Upon this stick A, (Plate II. Fig. 12.) which, of itself, would fall, because its center of gravity hangs over the table EF, I suspend a bucket B, fixing

another ſtick *a*, one end in a notch at *k*, and the other againſt the inside of the pail at the bottom. Now you will ſee that the bucket will, in this poſition, be ſupported, though filled with water. For the bucket being puſhed a little out of the perpendicular, by the ſtick *a*, the center of gravity of the whole is brought under the table, and conſequently ſupported by the table.

The knowledge of the principle of the center of gravity in bodies, will enable you to explain the ſtructure of a variety of toys which are put into the hands of children, ſuch as the *little ſawyer*; *rope-dancer*; *tumbler*, *&c.*

CONVERSATION XI.

On the Laws of Motion.

CHARLES. Are you now going, papa, to defcribe thofe machines, which you call *mechanical powers?*

Father. We muft, I believe, defer that a day or two longer, as I have a few more general principles with which I wifh you previoufly to be acquainted.

Emma. What are thefe, papa?

Father. In the firft place, you muft well underftand what are denominated the three general laws of

motion: the firſt of which is, "*that every body will continue in its ſtate of reſt, or of uniform motion, until it is compelled by ſome force to change its ſtate**."

Charles. There is no difficulty of conceiving that a body, as this ink-ſtand, in a ſtate of reſt muſt always remain ſo, if no external force be impreſſed upon it to give it motion. But I know of no example which will lead me to ſuppoſe, that a

* The Author is aware that this law of motion is not admitted by ſome modern philoſophers of high name; to him, however, their reaſonings appear inconcluſive. At any rate, in a work intended for very young minds, he thinks it a duty to avoid metaphyſical diſtinctions: preferring, at all times, rather to guide them by matters of fact, than to load their tender memories with curious and ſubtile theories.

body once put into motion would of itſelf continue ſo.

Father. You will, I think, preſently admit the latter part of the aſſertion as well as the former, although it cannot be eſtabliſhed by experiment.

Emma. I ſhall be glad to hear how this is.

Father. You will not deny that the ball which you ſtrike from the trap, has no more power either to deſtroy its motion, or cauſe any change in its velocity, than it has to change its ſhape.

Charles. Certainly, nevertheleſs, in a few ſeconds after I have ſtruck the ball with all my force, it falls to the ground, and then ſtops.

Father. Do you find no difference in the time that is taken up

before it comes to reſt, even ſuppoſing your blow the ſame?

Charles. Yes, if I am playing on the graſs it rolls to a leſs diſtance, than when I play on the ſmooth gravel.

Father. You find a like difference when you are playing at marbles, if you play in the gravel court, or on the even pavement in the arcade.

Charles. The marbles run ſo eaſily on the ſmooth ſtones in the arcade, that we can ſcarcely ſhoot with a force ſmall enough.

Emma. And I remember Charles and my couſin were, laſt winter, trying how far they could ſhoot their marbles along the ice in the canal; and they went a prodigious diſtance, in compariſon of that which

they would have gone on the gravel, or even on the pavement in the arcade.

Father. Now thefe inftances properly applied will convince you, that a body once put into motion, would go on for ever, if it were not compelled by fome external force to change its ftate.

Charles. I perceive what you are going to fay :—it is the rubbing or friction of the marbles, againft the ground which does the bufinefs. For on the pavement there are fewer obftacles than on the gravel, and fewer on the ice than on the pavement; and hence you would lead us to conclude, that if all obftacles were removed, they might proceed on for ever. But what are we to fay of the ball, what ftops that?

Father. Befides friction, there is another and ftill more important circumftance to be taken into confideration, which affects the ball, marbles, and every body in motion.

Charles. I underftand you, that is the attraction of gravitation.

Father. It is: for from what we faid when we converfed on that fubject, it appeared that gravity has a tendency to bring every body in motion to the earth; confequently, in a few feconds, your ball muft come to the ground by that caufe alone; but befides the attraction of gravitation, there is the refiftance which the air, through which the ball moves, makes to its paffage.

Emma. That cannot be much, I think.

Father. Perhaps, with regard to the ball ſtruck from your brother's trap, it is of no great conſideration, becauſe the velocity is but ſmall; but in all great velocities, as that of a ball from a muſket or cannon, there will be a material difference between the theory and practice, if it be neglected in the calculation. Move your mama's riding-whip through the air ſlowly, and you obſerve nothing to remind you that there is this reſiſting medium; but if you ſwing it with conſiderable ſwiftneſs, the noiſe which it occaſions, will inform you of the reſiſtance it meets with from ſomething, which is the atmoſphere.

Charles. If I now underſtand you, the force which compels a body in motion to ſtop, is of three kinds;

(1.) the attraction of gravitation;—(2.) the reſiſtance of the air;—and (3.) the reſiſtance it meets with from friction.

Father. You are quite right.

Charles. I have now no difficulty of conceiving, that a body in motion, will not come to a ſtate of reſt, till it is brought to it by an external force, acting upon it in ſome way or other. I have ſeen a gentleman, when ſkaiting on very ſlippery ice, go a great way without any exertion to himſelf, but where the ice was rough, he could not go half the diſtance without making freſh efforts.

Father. I will mention another inſtance or two on this law of motion. Put a baſin of water into your little ſiſter's waggon, and when the water is perfectly ſtill, move the waggon,

and the water, refifting the motion of the veffel, will at firft rife up in the direction, contrary to that in which the veffel moves. If, when the motion of the veffel is communicated to the water, you fuddenly ftop the waggon, the water, in endeavouring to continue the ftate of motion, rifes up on the oppofite fide.

In like manner, if while you are fitting quietly on your horfe, the animal ftarts forward, you will be in danger of falling off backward; but if while you are galloping along, the animal ftops on a fudden, you will be liable to be thrown forward.

Charles. This I know by experience, but I was not aware of the reafon of it till to-day.

Father. One of the firft, and not leaft important ufes of the principles

of natural philoſophy is, that they may be applied to, and will explain many of the common concerns of life.

We now come to the *ſecond* law of motion, which is;—"*that the change of motion, is proportional to the force impreſſed, and in the direction of that force.*"

Charles. There is no difficulty in this, for if while my cricket-ball is rolling along, after Henry has ſtruck it, I ſtrike it again, it goes on with increaſed velocity, and that in proportion to the ſtrength which I exert on the occaſion; whereas, if while it is rolling, I ſtrike it back again, or give it a ſide blow, I change the direction of its courſe.

Father. In the ſame way, gravity, and the reſiſtance of the at-

mosphere, change the direction of a cannon-ball from its course in a straight line, and bring it to the ground; and the ball goes to a farther or less distance, in proportion to the quantity of powder used.

The *third* law of motion is;— "*that to every action of one body upon another, there is an equal and contrary re-action.*" If I strike this table, I communicate to it, (which you perceive by the shaking of the glasses) the motion of my hand: and the table re-acts against my hand, just as much as my hand acts against the table.

If you press with your finger one scale of a balance, to keep it in equilibrio with a pound weight in the other scale, you will perceive, that the scale pressed by the finger, acts

againſt it with a force equal to a pound, with which the other ſcale endeavours to deſcend.

A horſe drawing a heavy load, is as much drawn back by the load as he draws it forward.

Emma. I do not comprehend how the cart draws the horſe.

Father. But the progreſs of the horſe is impeded by the load, which is the ſame thing: for the force which the horſe exerts would carry him to a greater diſtance in the ſame time, were he freed from the incumbrance of the load, and therefore, as much as his progreſs falls ſhort of that diſtance, ſo much is he, in effect, drawn back by the re-action of the loaded cart.

Again, if you and your brother were in a boat, and if, by means of

a rope, you were to attempt to draw another to you, the boat in which you were would be as much pulled toward the empty boat as that would be moved to you; and if the weights of the two boats were equal, they would meet in a point half way between the two.

If you ſtrike a glaſs bottle with an iron hammer, the blow will be received by the hammer and the glaſs; and it is immaterial whether the hammer be moved againſt the bottle at reſt, or the bottle be moved againſt the hammer at reſt, yet the bottle will be broken, though the hammer be not injured, becauſe the ſame blow, which is ſufficient to break glaſs, is not ſufficient to break or injure a lump of iron.

From this law of motion you may learn in what manner a bird, by the ſtroke of its wings, is able to ſupport the weight of its body.

Charles. Pray explain this, papa.

Father. If the force with which it ſtrikes the air below it, is *equal* to the weight of its body, then the reaction of the air upwards is likewiſe equal to it; and the bird being acted upon by two *equal* forces in contrary directions, will reſt between them. If the force of the ſtroke is *greater* than its weight, the bird will riſe with the *difference* of theſe two forces: and if the ſtroke be *leſs* than its weight, then it will ſink with the *difference*.

CONVERSATION XII.

On the Laws of Motion.

Charles. Are thofe laws of motion which you explained yefterday, of great importance in natural philofophy?

Father. Yes, they are, and fhould be carefully committed to memory. They were affumed by Sir I. Newton, as the fundamental principles of mechanics, and you will find them at the head of all books written on thefe fubjects. From thefe alfo, we are naturally led to fome other branches of fcience, which, though we cannot but flightly mention, fhould not be wholly neglected.

They are, in fact, but corollaries to the laws of motion.

Emma. What is a corollary, papa?

Father. It is nothing more than ſome truth clearly deducible from ſome other truth before demonſtrated or admitted. Thus by the *firſt* law of motion, *every body muſt endeavour to continue in the ſtate, into which it is put, whether it be of reſt, or uniform motion in a ſtraight line:* from which it follows as a corollary, that when we ſee a body move in a curve line, it muſt be acted upon by at leaſt two forces.

Charles. When I whirl a ſtone round in a ſling, what are the two forces which act upon the ſtone?

Father. There is the force, by which, if you let go the ſtring, the

ſtone will fly off in a right line; and there is the force of the hand, which keeps it in a circular motion.

Emma. Are there any of theſe circular motions in nature?

Father. The moon, and all the planets move by this law:—to take the moon as an inſtance. It has a conſtant tendency to the earth, by the attraction of gravitation, and it has alſo a tendency to proceed in a right line, by that projectile force impreſſed upon it by the Creator, in the ſame manner as the ſtone flies from your hand; now, by the joint action of theſe two forces it deſcribes a circular motion.

Emma. And what would be the conſequence, ſuppoſing the projectile force to ceaſe?

Father. The moon muſt fall to

the earth; and if the force of gravity were to ceafe acting upon the moon, it would fly off into infinite fpace. Now the projectile force, when applied to the planets, is called the *centrifugal* force, as having a tendency to recede or fly from the center; and the other force is termed the *centripetal* force, from its tendency to fome point as a center.

Charles. And all this is in confequence of the inactivity of matter, by which bodies have a tendency to continue in the fame ftate they are in, whether of reft or motion?

Father. You are right, and this principle which Sir I. Newton affumed to be in all bodies, he called their *vis inertiæ.*

Charles. A few mornings ago, you fhewed us that the attraction

of the earth upon the moon* is 3600 times lefs, than it is upon heavy bodies near the earth's furface. Now as this attraction is meafured by the fpace fallen through in a given time, I have endeavoured to calculate the fpace which the moon would fall through in a minute, were the projectile force to ceafe.

Father. Well, and how have you brought it out?

Charles. A body falls here 16 feet in the firft fecond, confequently in a minute, or 60 feconds, it would fall 60 times 60 feet, multiplied by 16, that is 3600 feet, which is to be multiplied by 16; and as the moon would fall through 3600 times lefs fpace in a given time than a

* See Converfation IV.

body here, it would fall only 16 feet in the firſt *minute.*

Father. Your calculation is accurate. I will recall to your mind the *ſecond* law, by which it appears, *that every motion, or change of motion produced in a body, muſt be proportional to, and in the direction of the force impreſſed.* Therefore, if a moving body receives an impulſe in the direction of its motion, its velocity will be increaſed;—if, in the contrary direction, its velocity will be diminiſhed;—but if the force be impreſſed in a direction oblique to that in which it moves; then its direction will be between that of its former motion, and that of the new force impreſſed.

Charles. This I know from the

obſervations I have made with my cricket-ball.

Father. By this ſecond law of motion, you will eaſily underſtand, that if a body at reſt, receives two impulſes, at the ſame time, from forces whoſe directions do not coincide, it will, by their joint action, be made to move in a line that lies between the direction of the forces impreſſed.

Emma. Have you any machine to prove this ſatisfactorily to the ſenſes?

Father. There are many ſuch invented by different perſons, deſcriptions of which, you will hereafter find in various books on theſe ſubjects. But it is eaſily underſtood by a figure. If on the ball A, (Plate II. Fig. 14.) a force be impreſſed, ſufficient to

make it move with an uniform velocity to the point B, in a ſecond of time; and if another force be alſo impreſſed on the ball, which alone would make it move to the point C, in the ſame time; the ball, by means of the two forces, will deſcribe the line AD, which is a diagonal of the figure, whoſe ſides are AC and AB.

Charles. But how then is motion produced in the *direction of the force?* according to the ſecond law, it ought to be in one caſe, in the direction AC, and in the other, in that of AB, whereas, it is in that of AD?

Father. Examine the figure a little attentively, carrying this in your mind, that for a body to move in the *ſame direction*, it is *not* neceſſary

that it ſhould move in the *ſame ſtraight line;* but that it is ſufficient to move *either* in that line, or in any one parallel to it.

Charles. I perceive then that the ball when arrived at D, has moved in the direction AC, becauſe BD is parallel to AC; and alſo in the direction AB, becauſe CD is parallel to it.

Father. And in no other poſſible ſituation but at the point D, could this experiment be conformible to the ſecond law of motion.

CONVERSATION XIII.

Of the Laws of Motion.

FATHER. If you reflect a little upon what we said yesterday on the second law of motion, you will readily deduce the following corollaries. Plate II. Fig. 14.

1. That if the forces be equal, and act at right angles to one another, the line described by the ball will be the diagonal of a *square*. But in all other cases, it will be the diagonal of a parallelogram of some kind.

2. By varying the angle, and the forces, you vary the form of your parallelogram.

Charles. Yes, papa, and I ſee another conſequence, viz. that the motions of two forces acting conjointly in this way, are not ſo great as when they act ſeparately.

Father. That is true, and you are led to the concluſion, I ſuppoſe, from the recollection that in every triangle any two ſides taken together are greater than the remaining ſide; and therefore you infer, and juſtly too, that the motions which the ball A muſt have received, had the forces been applied ſeparately, would have been equal to AC and AB, or, which is the ſame thing, to AC, and CD, the two ſides of the triangle ADC, but by their joint action, the motion is only equal to AD, the remaining ſide of the triangle.

Hence then you will remember, that in the *compoſition*, or adding together of forces (as this is called) motion is always loſt: and in the *reſolution* of any one force as AD, into two others AC and AB, motion is gained.

Charles. Well, papa, but how is it that the heavenly bodies, the moon for inſtance, which is impelled by two forces, performs her motion in a circular curve round the earth, and not in a diagonal between the direction of the projectile force, and that of the attraction of gravity to the earth?

Father. Becauſe in the caſe juſt mentioned, there was but the action of a ſingle impulſe in each direction, whereas the action of gravity on the moon, is continual, and cauſes an

accelerated motion, and hence the line is a curve.

Charles. Supposing then, that A reprefent the moon, and AC the fixteen feet through which it would fall in a minute by the attraction of gravity towards the earth, and AB reprefent the projectile force acting upon it for the fame time. If AB and AC acted as fingle impulfes, the moon would in that cafe defcribe the diagonal AD: but fince thefe forces are conftantly acting, and that of gravity is an accelerating force alfo, therefore inftead of the ftraight line AD, the moon will be drawn into the curve line A*a*D. Do I underftand the matter right?

Father. You do; and hence you eafily comprehend how by good inftruments, and calculation, the at-

traction of the earth upon the moon was discovered.

The *third* law of motion, viz. *that action and re-action are equal and in contrary directions*, may be illustrated by the motion communicated by the percussion of *elastic* and *non-elastic* bodies.

Emma. What are these, papa?

Father. *Elastic* bodies, are those which have a certain spring, by which their parts, upon being pressed inwards, by percussion, return to their former state, this property is evident in a ball of wool or cotton; or in spunge compressed. *Non-elastic* bodies are those which, when one strikes another, do not rebound, but move together after the stroke.

Let two equal ivory balls *a* and *b* be suspended by threads; if *a* (Plate

II. Fig 15.) be drawn a little out of the perpendicular, and let fall upon *b*, it will loſe its motion by communicating it to *b*, which will be driven to a diſtance *c*, equal to that through which *a* fell; and hence it appears that the re-action of *b*, was equal to the action of *a* upon it.

Emma. But do the parts of the ivory balls yield by the ſtroke, or, as you call it, by the percuſſion?

Father. They do; for if I lay a little paint on *a*, and let it *touch* *b*, it will make but a very ſmall ſpeck upon it: but if it *fall* upon *b*, the ſpeck will be much larger; which proves that the balls are elaſtic, and that a little hollow, or dint, was made in each by colliſion. If now two equal ſoft balls of clay, or glazier's putty, which are non-elaſtic,

meet each other with equal velocities, they would ſtop and ſtick together at the place of their meeting, as their mutual actions deſtroy each other.

Charles. I have ſometimes ſhot my white alley againſt another marble ſo plumply, that the marble has gone off as ſwiftly as the alley approached it, and that remained in the place of the marble. Are marbles therefore, as well as ivory, elaſtic?

Father. They are.—If three elaſtic balls *a*, *b*, *c* (Plate III. Fig. 16.) be hung from adjoining centers, and *c* be drawn a little out of the perpendicular, and let fall upon *b*, then will *c* and *b* become ſtationary, and *a* will be driven to *o*, the diſtance through which *c* fell upon *b*.

If you hang any number of balls, as ſix, eight, &c. ſo as to touch each other, and if you draw the outſide one away to a little distance, and then let it fall upon the others, the ball on the oppoſite ſide will be driven off, while the reſt remain ſtationary, ſo equally is the action and re-action of the ſtationary balls divided among them. In the ſame manner, if two are drawn aſide and ſuffered to fall on the reſt, the oppoſite two will fly off, and the others remain ſtationary.

There is one other circumſtance depending upon the action, and re-action of bodies, and alſo upon the *vis inertiæ* of matter, worth noticing: by ſome authors you will find it largely treated upon.

If I ſtrike a blackſmith's anvil with a hammer, action and re-action

being equal, the anvil ſtrikes the hammer as forcibly as the hammer ſtrikes the anvil.

If that anvil be large enough, I might lay it on my breaſt, and ſuffer you to ſtrike it with a ſledge hammer with all your ſtrength, without pain or riſque, for the *vis inertiæ* of the anvil reſiſts the force of the blow. But if the anvil were but a pound or two in weight, your blow would probably kill me.

CONVERSATION XIV.

On the Mechanical Powers.

CHARLES. Will you now, papa, explain the mechanical powers?

Father. I will, and I hope you have not forgotten what the *momentum* of a body is.

Charles. No, it is the force of a moving body, which force is to be eſtimated by the weight, multiplied into its velocity.

Father. Then a ſmall body may have an equal momentum with one much larger?

Charles. Yes, provided the ſmaller body moves as much ſwifter than

the larger one, as the weight of the latter is greater than that of the former.

Father. What do you mean when you ſay that one body moves ſwifter, or has a greater velocity than another?

Charles. That it paſſes over a greater ſpace in the ſame time. Your watch will explain my meaning: the minute-hand travels round the dial-plate in an hour, but the hour-hand takes twelve hours to perform its courſe in, conſequently, the velocity of the minute-hand is twelve times greater than that of the hour-hand; becauſe, in the ſame time, viz. twelve hours, it travels twelve times the ſpace that is gone through by the hour-hand.

Father. But this can be only

true on the fuppofition, that the two circles are equal. In my watch, the minute-hand is longer than the other, and confequently, the circle defcribed by it, is larger than that defcribed by the hour-hand.

Charles. I fee at once, that my reafoning holds good only in the cafe where the hands are equal.

Father. There is, however, a particular point of the longer hand, of which it may be faid, with the ftricteft truth, that it has exactly twelve times the velocity of the extremity of the fhorter.

Charles. That is the point, at which, if the remainder were cut off, the two hands would be equal. And in fact, every different point of the hand, defcribes different fpaces in the fame time.

Father. The little pivot on which the two hands ſeem to move, (for they are really moved by different pivots, one within another,) may be called the *center of motion*, which is a fixed point; and the longer the hand is, the greater is the ſpace deſcribed.

Charles. The extremities of the vanes of a wind-mill, when they are going very faſt, are ſcarcely diſtinguiſhable, though the ſeparate parts, nearer the mill, are eaſily diſcerned; this is owing to the veloeity of the extremities, being ſo much greater than that of the other parts.

Emma. Did not the ſwiftneſs of the round-abouts, which we ſaw at the fair, depend on the ſame principle, viz. the length of the poles upon which the ſeats were fixed?

Father. Yes, the greater the diſtance, at which theſe ſeats were placed, from the center of motion, the greater the ſpace which the little boys and girls travelled for their halfpenny.

Emma. Then thoſe in the ſecond row, had a ſhorter ride for their money, than thoſe at the end of the poles.

Father. Yes, ſhorter as to ſpace, but the ſame as to time. In the ſame way, when you and Charles go round the gravel-walk for half an hour's exerciſe, if he run, while you walk, he will, perhaps, have gone ſix or eight times round, in the ſame time that you have been but thrice or four times; now, as to time, your exerciſe has been equal,

but he may have paſſed over double the ſpace in the ſame time.

Charles. How does this apply to the explanation of the mechanical powers?

Father. You will find the application very eaſy:—without clear ideas of what is meant by *time* and *ſpace,* it were in vain to expect you to comprehend the principles of mechanics.

There are ſix mechanical powers. The lever; the wheel and axle; the pulley; the inclined plane; the wedge; and the ſcrew.

Emma. Why are they called mechanical powers?

Father. Becauſe, by their means, we are enabled *mechanically* to raiſe weights, move heavy bodies, and overcome reſiſtances, which, with-

out their aſſiſtance, could not be done.

Charles. But is there no limit to the aſſiſtance gained by theſe powers? for I remember reading of Archimedes, who ſaid, that with a place for his fulcrum he would move the earth itſelf.

Father. Human power, with all the aſſiſtance which art can give, is very ſoon limited, and upon this principle, *that what we gain in power, we loſe in time.* That is, if by your own unaſſiſted ſtrength, you are able to raiſe fifty pounds to a certain diſtance in one minute, and if by the help of machinery, you wiſh to raiſe 500 pounds to the ſame height, you will require ten minutes to perform it in; thus you increaſe your power ten-fold, but it

it is at the expence of time. Or in other words, you are enabled to do that with one effort in ten minutes, which you could have done in ten feparate efforts in the fame time.

Emma. The importance of mechanics, then, is not fo very confiderable as one, at firft fight, would imagine; fince there is no real gain of force acquired by the mechanical powers.

Father. Though there be not any actual increafe of force gained by thefe powers; yet, the advantages which men derive from them are ineftimable. If there are feveral fmall weights, manageable by human ftrength, to be raifed to a certain height, it may be full as convenient to elevate them one by one, as to take the advantage of the mechanical

powers, in raiſing them all at once. Becauſe, as we have ſhewn, the ſame time will be neceſſary in both caſes. But ſuppoſe you have a large block of ſtone of a ton weight to carry away, or a weight ſtill greater, what is to be done?

Emma. I did not think of that.

Father. Bodies of this kind cannot be ſeparated into parts proportionable to the human ſtrength without immenſe labour, nor, perhaps, without rendering them unfit for thoſe purpoſes for which they are to be applied. Hence then you perceive the great importance of the mechanical powers, by the uſe of which, a man is able with eaſe to manage a weight many times greater than himſelf.

Charles. I have, indeed, ſeen a few men, by means of pulleys, and ſeemingly with no very great exertion, raiſe an enormous oak into a timber-carriage, in order to convey it to the dock-yard.

Father. A very excellent inſtance; for if the tree had been cut into ſuch pieces, as could have been managed by the natural ſtrength of theſe men, it would not have been worth carrying to Deptford or Chatham for the purpoſe of ſhip-building.

Emma. I acknowledge my error; —what is a fulcrum, papa?

Father. It is a *fixed point,* or prop, round which the other parts of a machine move.

Charles. The pivot, upon which the hands of your watch move, is a fulcrum then?

Father. It is, and you remember we called it alſo the center of motion;—the rivet of theſe ſciſſars is alſo a fulcrum.

Emma. Is that a fixed point, or prop?

Father. Certainly it is a fixed point, as it regards the two parts of the ſciſſars; for that always remains in the ſame poſition, while the other parts move about it. Take the poker and ſtir the fire, now that part of the bar on which the poker reſts is a fulcrum, for the poker moves upon it as a center.

CONVERSATION XV.

Of the Lever.

FATHER. We will now confider the *Lever*, which is generally called the first mechanical power.

The *lever* is any inflexible bar of wood, iron, &c. which ferves to raife weights, while it is fupported at a point by a prop or fulcrum, on which, as the center of motion, all the other parts turn. AB (Plate 111. Fig. 17.) will reprefent a lever, and the point c the fulcrum or center of motion. Now, it is evident, if the lever turn on its center of mo-

tion C, so that A comes into the position *a*; B at the same time must come into the position *b*. If both the arms of the lever be equal, that is, if AC is equal to BC, there is no advantage gained by it, for they pass over equal spaces in the same time; and according to the fundamental principle already laid down (p. 127) "as advantage or power is gained, time must be lost:" therefore no time being lost by a lever of this kind, there can be no power gained.

Charles. Why then is it called a mechanical power?

Father. Strictly speaking perhaps it ought not be numbered as one. But it is usually reckoned among them, having the fulcrum between the weight and the power, which is the distinguishing property of levers

of the firſt kind. And when the fulcrum is exactly the middle point between the weight and power it is the common balance: to which, if ſcales be ſuſpended at A and B, it is fitted for weighing all ſorts of commodities.

Emma. You ſay it is a lever of the *firſt* kind, are there ſeveral ſorts of levers?

Father. There are three ſorts; ſome perſons reckon four, the fourth however, is but a bended one of the firſt kind. A lever of the *firſt* kind (Plate 111. Fig. 17, 18.) has the fulcrum between the weight and power.

The *ſecond* kind of lever (Plate 111. Fig. 20.) has the fulcrum at one end, the power at the other, and the weight between them.

In the *third* kind (Plate III. Fig. 21.) the power is between the fulcrum and the weight.

Of Lever's powers the different ſorts are three,
The *firſt* in ſteel-yards and in ſcales you ſee;
The beſt a *ſecond* is the miller's lift
Where *power* and *fulcrum* to each end you ſhift;
And in the *third*, the worſt of all my friends,
You find the *weight* and *fulcrum* at each end.

Let us take the lever of the firſt kind, (Fig. 18.) which if it be moved into the poſition *a b*, by turning on its fulcrum C, it is evident that while A has travelled over the ſhort ſpace A *a*, B has travelled over the greater ſpace B *b*, which ſpaces are to one another, exactly in proportion to the length of the arms AC and BC. If now you apply your

hand first to the point A, and afterwards to B, in order to move the lever into the position *a b*, using the same velocity in both cases, you will find that the time spent in moving the lever when the hand is at B, will be as much greater, as that spent when the hand is at A, as the arm BC is longer than the arm AC, but then the exertion required will, in the same proportion, be less at B than at A.

Charles. The arm BC appears to be four times the length of AC.

Father. Then it is a lever which gains power in the proportion of four to one. That is, a single pound weight applied to the end of the arm BC, as at P, will balance four pounds suspended at A, as W.

Charles. I have feen workmen move large pieces of timber to very fmall diftanees, by means of a long bar of wood or iron; is that a lever?

Father. It is; they force one end of the bar under the timber, and then place a block of wood, ftone, &c. beneath, and as near the fame end of the lever as poffible, for a fulcrum, applying their own ftrength to the other: and power is gained in proportion as the diftanee from the fulcrum to the part where the men apply their ftrength, is greater than the diftance from the fulcrum to that end under the timber.

Charles. It muft be very confiderable, for I have feen two or three men, move a tree, in this way, of feveral tons weight I fhould think.

Father. That is not difficult; for ſuppoſing a lever to gain the advantage of twenty to one, and a man by his natural ſtrength is able to move but a hundred weight, he will find that by a lever of this ſort, he can move twenty hundred weight or a ton; but for ſingle exertions, a ſtrong man can put forth a much greater power, than that which is ſufficient to remove a hundred weight; and levers are alſo frequently uſed, the advantage gained by which is ſtill more conſiderable than twenty to one.

Charles. I think, you ſaid the other day, that the common ſteel-yard made uſe of by the butcher, is a lever.

Father. I did; the ſhort arm AC (Plate III. Fig. 19.) is, by an in-

creafe in fize, made to balance the longer one BC, and from C the center of motion, the divifions muft commence. Now if BC be divided into as many parts as it will contain, each equal to AC; a fingle weight as a pound P, will ferve for weighing any thing as heavy as itfelf, or as many times heavier as there are divifions in the arm C. If the weight P be placed at the divifion one in the arm BC, it will balance one pound in the fcale at A; if it be removed to 3, 5, or 7, it will balance 3, 5, or 7 pounds in the fcale, for thefe divifions being refpectively 3, 5, or 7 times the diftance from the center of motion C, that A is, it becomes a lever, which gains advantage, at thofe points, in the proportion of 3, 5, and 7. If now the intervals

between the divifions on the longer arm be fub-divided into halves, quarters, &c. any weight may be accurately afcertained to halves, quarters of pounds, &c.

CONVERSATION XVI.

Of the Lever.

EMMA. What advantage has the ſteel-yard, which you deſcribed in our laſt converſation, over a pair of ſcales?

Father. It may be much more readily removed from place to place; it requires no apparatus, and only a ſingle weight for all the purpoſes to which it can be applied.—Sometimes the arms are not of equal weight. In that caſe the weight P muſt be moved along the arm AC, till it exactly balance the other arm

without a weight, and in that point a notch muſt be made, marking over it a cypher 0, from whence the diviſions muſt commence.

Charles. Does there require great accuracy in the manufacture of inſtruments of this kind?

Father. Yes, of ſuch importance is it to the public, that there ſhould be no error or fraud by means of falſe weights, or falſe balances, that it is the buſineſs of certain public officers to examine at ſtated ſeaſons the weights, meaſures, &c. of every ſhop-keeper in the land. Yet it is to be feared that after all precautions much fraud is practiſed upon the unſuſpecting.

Emma. I one day laſt ſummer bought, as I ſuppoſed, a pound of cherries at the door, but Charles

thinking there were not a pound, we tried them in your ſcales and found but twelve ounces, or three quarters, inſtead of a pound, and yet the ſcale went down as if the man had given me full weight. How was that managed?

Father. It might be done many ways: by ſhort weights;—or by the ſcale in which the fruit was put, being heavier than the other;—but fraud may be practiſed with good weights and even ſcales, by making the arm of the balance, on which the weights hang, ſhorter than the other, for then a pound weight will be balanced by as much leſs fruit than a pound, as that arm is ſhorter than the other; this was probably the method by which you were cheated.

Emma. By what method could I have difcovered this cheat?

Father. The fcales when empty are exactly balanced, but when loaded, though ftill in equilibrio, the weights are unequal, and the deceit is inftantly dfcovered by changing the weights to the contrary fcales. I will give you a rule to find the true weight of any body by fuch a falfe balance, the reafon of the rule you will underftand hereafter, "*find the weights of the body by both fcales, multiply them together, and then find the fquare root of the product, which is the true weight.*"

Charles. Let me fee if I underftand the rule: fuppofe a body weigh 16 ounces in one fcale, and in the other 12 ounces and a quarter, I multiply 16 by 12 and a quarter, and

I get the product 196, the square root of which is 14: for 14 multiplied into itself gives 196; therefore the true weight of the body is 14 ounces.

Father. That is just what I meant. —To the lever of the first kind may be referred many common instruments, such as sciffars, pincers, snuffers, &c. which are made of two levers, acting contrary to one another.

Emma. The rivet is the fulcrum, or center of motion, the hand the power used, and whatever is to be cut, is the resistance to be overcome.

Charles. A poker stirring the fire is also a lever, for the bar is the fulcrum, the hand the power, and the coals the resistance to be overcome.

Father. We now proceed to levers of the second kind, in which the fulcrum c (Fig. 20.) is at one end, the

power P applied at the other B, and the weight to be raiſed W, ſomewhere between the fulcrum and the power.

Charles. And how is the advantage gained to be eſtimated in this lever?

Father. By looking at the figure you will find that power or advantage is gained in proportion as the diſtance of the power P is greater than the diſtance of the weight W from the fulcrum.

Charles. Then if the weight hang at one inch from the fulcrum, and the power acts at five inches from it, the power gained is five to one, or one pound at P will balance five at W?

Father. It will; for you perceive that the power paſſes over five times as great a ſpace as the weight, or

while the point A in the lever moves over one inch, the point B will move over five inches.

Emma. What things in common uſe are to be referred to the lever of the ſecond kind?

Father. The moſt common and uſeful of all things; every door for inſtance which turns on hinges is a lever of this ſort. The hinges may be conſidered as the fulcrum or center of motion, the whole door is the weight to be moved, and the power is applied to that ſide on which the lock is uſually fixed.

Emma. Now I ſee the reaſon why there is conſiderable difficulty in puſhing open a heavy door, if the hand is applied to the part next the hinges, although it may be opened

with the greateſt eaſe in the uſual method.

Charles. This ſofa, with ſiſter upon it, repreſents a lever of the ſecond kind.

Father. Certainly, if while ſhe is ſitting upon it, in the middle, you raiſe one end, while the other remains fixed as a prop or fulcrum. To this kind of lever may be alſo reduced nut-crackers; oars; rudders of ſhips; thoſe cutting knives which have one end fixed in a block, ſuch as are uſed for cutting chaff, drugs, wood for pattens, &c.

Emma. I do not ſee how oars and rudders are levers of this ſort.

Father. The boat is the weight to be moved, the water is the fulcrum, and the waterman at the handle the power. The maſts of ſhips are alſo

levers of the ſecond kind, for the bottom of the veſſel is the fulcrum, the ſhip the weight, and the wind acting againſt the ſail is the moving power.

The knowledge of this principle may be uſeful in many ſituations and circumſtances of life:—if two men unequal in ſtrength have a heavy burden to carry on a pole between them, the ability of each may be conſulted, by placing the burden as much nearer to the ſtronger man, as his ſtrength is greater than that of his partner.

Emma. Which would you call the prop in this caſe?

Father. The ſtronger man, for the weight is neareſt to him, and then the weaker muſt be conſidered as the power. Again, two horſes may be

ſo yoked to a carriage that each ſhall draw a part proportional to his ſtrength by dividing the beam in ſuch a manner, that the point of *traction*, or drawing, may be as much nearer to the ſtronger horſe than to the weaker, as the ſtrength of the former exceeds that of the latter.

We will now deſcribe the third kind of lever. In this the prop or fulcrum C (Fig. 21.) is at one end, the weight W at the other, and the power P is applied at B ſomewhere between the prop and weight.

Charles. In this caſe, the weight being farther from the center of motion than the power, muſt paſs through more ſpace than it.

Father. And what is the conſequence of that?

Charles. That the power muſt be greater than the weight, and as much greater as the diſtance of the weight from the prop exceeds the diſtance of the power from it, that is, to balance a weight of three pounds at A, there will require the exertion of a power P, acting at B, equal to five pounds.

Father. Since then a lever of this kind is a diſadvantage to the moving power, it is but ſeldom uſed, and only in caſes of neceſſity; ſuch as in that of a ladder, which being fixed at one end againſt a wall or other obſtacle, is by the ſtrength of a man's arm raiſed into a perpendicular ſituation. But the moſt important application of this third kind of lever, is manifeſt in the ſtructure of the limbs of animals, particularly in thoſe of man; to take

the arm as an inftance: when we lift a weight by the hand, it is effected by means of mufcles coming from the fhoulder blade, and terminating about one tenth as far below the elbow as the hand is: now the elbow being the center of motion round which the lower part of the arm turns, according to the principle juft laid down, the mufcles muft exert a force ten times as great as the weight that is raifed. At firft view this may appear a difadvantage, but what is loft in power is gained in velocity, and thus the human figure is better adapted to the various functions it has to perform.

CONVERSATION XVII.

Of the Wheel and Axis.

FATHER. Well, Emma, do you underſtand the principle of the lever, which we diſcuſſed ſo much at large yeſterday?

Emma. The lever gains advantage, in proportion to the ſpace paſſed through by the acting power; that is, if the weight to be raiſed, be at the diſtance of one inch from the fulcrum, and the power is applied nine inches diſtant from it, then it is a lever, which gains advantage as 9 to 1, becauſe the ſpace paſſed through

by the *power* is nine times greater than that paſſed through by the weight; and, therefore, what is loſt in time, by paſſing through a greater ſpace, is gained in power.

Father. You recollect alſo, what the different kinds of levers are, I hope.

Emma. I ſhall never ſee the fire ſtirred without thinking of a ſimple lever of the firſt kind; my ſciſſars will frequently remind me of a combination of two levers of the ſame ſort. The opening and ſhutting of the door, will prevent me from forgetting the nature of the lever of the ſecond kind; and, I am ſure that I ſhall never ſee a workman raiſe a ladder againſt a houſe, without recollecting the third ſort of lever. Be-

fides, I believe a pair of tongs is a lever of this kind.

Father. You are right, for the fulcrum is at the joint, and the power is applied between that, and the parts ufed in taking up coals, &c.—Can you, Charles, tell us how the principle of *momentum* applies to the lever?

Charles. The *momentum* of a body is eftimated by its weight, multiplied into its velocity; and the velocity muft be calculated by the fpace paffed through in a given time. Now, if I examine the lever, (Fig. 18. 20.) and confider it as an inflexible bar turning on a center of motion, it is evident, that the fame time is ufed for the motion both of the weight and the power, but the fpaces paffed over are very different;

that which the power paſſes through, being as much greater than that paſſed by the weight, as the length of the diſtance of the power from the prop, is greater than the diſtance of the weight from the prop; and the velocities being as the ſpaces paſſed in the ſame time, muſt be greater in the ſame proportion. Conſequently, the velocity of P, the power, multiplied into its weight, will be equal to the ſmaller velocity of W, multiplied into its weight, and thus their momenta being equal, they will balance one another.

Father. This applies to the firſt and ſecond kind of lever; what do you ſay to the third?

Charles. In the third, the velocity of the power P, (Fig. 21.) being leſs than that of the weight W,

it is evident, in order that their momenta may be equal, that the weight acting at P, muſt be as much greater than that of W, as AC is leſs than BC, and then they will be in equilibrio.

Father. The ſecond mechanical power is the *Wheel and Axis,* which gains power in proportion, as the circumference of the wheel is greater than that of the axis; this machine may be referred to the principle of the lever. AB (Plate III. Fig. 22.) is the wheel, CD its axis, and if the circumference of the wheel be eight times as great as that of the axis, then a ſingle pound P, will balance a weight W, of eight pounds.

Charles. Is it by an inſtrument of this kind that water is drawn from

thofe deep wells fo common in many parts of the country?

Father. It is; but as in moft cafes of this kind only a fingle bucket is raifed at once, there requires but little power in the operation, and therefore, inftead of a large wheel as AB, an iron handle fixed at Q is made ufe of, which, you know, by its circular motion, anfwers the purpofe of a wheel.

Charles. I once raifed fome water by a machine of this kind, and I found, that as the bucket afcended nearer the top the difficulty increafed.

Father. That muft always be the cafe, where the wells are fo deep as to caufe, in the afcent, the rope to coil more than once the length of

the axis, becaufe, the advantage gained is in proportion, as the circumference of the wheel is greater than that of the axis; fo that if the circumference of the wheel be 12 times greater than that of the axis, 1 pound applied at the former, will balance 12 hanging at the latter; but by the coiling of the rope round the axis, the *difference* between the circumference of the wheel, and that of the axis continually diminifhes, confequently the advantage gained is lefs every time a new coil of rope is wound on the whole length of the axis; this explains why the difficulty of drawing the water, or any other weight, increafes as it afcends nearer the top.

Charles. Then by diminiſhing the axis, or by increaſing the length of the handle, advantage is gained.

Father. Yes, by either of thoſe methods you may gain power, but it is very evident, that the axis cannot be diminiſhed beyond a certain limit, without rendering it too weak to ſuſtain the weight; nor can the handle be managed, if it be conſtructed on a ſcale much larger than what is commonly uſed.

Charles. We muſt, then, have recourſe to the wheel with ſpikes ſtanding out of it at certain diſtances from each other to ſerve as levers.

Father. You may by this means increaſe your power according to your wiſh, but it muſt be at the expence of time, for you know that a

ſimple handle may be turned ſeveral times, while you are pulling the wheel round once. To the principle of the *wheel and axis*, may be referred the capſtan, windlaſs, and all thoſe numerous kinds of cranes, which are to be ſeen at the different wharfs on on the banks of the Thames.

Rous'd from repoſe, aloft the ſailors ſwarm,
And with their *levers* ſoon the *windlaſs* arm.
The order given, up-ſpringing with a bound
They lodge the bars, and wheel their en-
gines round:
At every turn the clanging pauls reſound,
Uptorn reluctant from its oozy cave
The pond'rous anchor riſes o'er the wave.

FALCONER'S SHIPWRECK.

Charles. I have ſeen a crane, which conſiſts of a wheel large enough for a man to walk in.

Father. In this the weight of

the man, or men, (for there are ſometimes two or three) is the moving power; for, as the man ſteps forwards, the part upon which he treads becomes the heavieſt, and conſequently deſcends till it be the loweſt. On the ſame principle, you may ſee at the door of many bird-cage-makers, a bird, by its weight, give a wicker cage a circular motion; now, if there were a ſmall weight ſuſpended to the axis of the cage, the bird by its motion would draw it up, for as it hops from the bottom bar to the next, its *momentum* cauſes that to deſcend, and thus the operation is performed, both with regard to the cage, and to thoſe large cranes which you have ſeen.

Emma. Is there no danger if the man happens to ſlip?

Father. If the weight be very great, a ſlip with the foot may be attended with very dangerous conſequences. To prevent which, there is generally fixed at one end of the axis a little wheel G, (Fig. 22.) called a rachet-wheel; with a catch H, to fall in to its teeth; this will, at any time, ſupport the weight in caſe of an accident. Sometimes, inſtead of men walking within the great wheel, cogs are ſet round it on the outſide, and a ſmall trundle wheel made to work in the cogs, and to be turned by a winch.

Charles. Are there not other ſorts of cranes in which all danger is avoided?

Father. The crane is a machine of ſuch importance to the commercial concerns of this country, that new inventions of it are continually offered to the public: I will when we go to the library, ſhew you in the 10th. vol. of the Tranſactions of the Society for the Encouragement of Arts and Sciences, an engraving of a ſafe, and, I believe, truly excellent crane; it was invented by a friend of mine, Mr. James White, who poſſeſſed a moſt extraordinary genius for mechanics, and who, about twelve years ago, offered his ſervices to a noble Duke, then at the head of the Board of Ordnance, but they being rejected, he went to the Continent, where he is very profitably exerciſing his talents.

Charles. But you ſaid that this mechanical power might be conſidered as a lever of the firſt kind.

Father. I did; and if you conceive the wheel and axis (Fig. 22.) to be cut through the middle in the direction AB; FGB (Plate III. Fig. 23.) will repreſent a ſection of it. AB is a lever, whoſe center of motion is C; the weight W, ſuſtained by the rope AW, is applied at the diſtance CA the radius of the axis; and the power P, acting in the direction BP, is applied at the diſtance CB, the radius of the wheel; therefore, according to the principle of the lever, the power will balance the weight when it is as much leſs than the weight, as the diſtance CB is greater than the diſtance of the weight AC.

CONVERSATION XVIII.

Of the Pulley.

FATHER. The third mechanical power, the *pulley*, may be likewife explained on the principle of the lever. The line AB (Plate IV. Fig. 24.) may be conceived to be a lever, whofe arms AC and BC are equal, and C the fulcrum, or center of motion. If now two equal weights W and P, be hung on the cord paffing over the pulley, they will balance one another, and the fulcrum will fuftain both.

Charles. This pulley then, like the common ballance, gives no advantage.

Father. From the ſingle *fixed* pulley no mechanical advantage is derived; it is, nevertheleſs, of great importance in changing the direction of a power, and is very much uſed in buildings for drawing up ſmall weights, it being much eaſier for a man to raiſe ſuch burdens by means of a ſingle pulley, than to carry them up a long ladder.

Emma. Why is it called a mechanical power?

Father. Though a ſingle fixed pulley gives no advantage, yet when it is not fixed, or when two or more are combined into what is called a ſyſtem of pulleys, they then poſſeſs all the properties of the other mecha-

nical powers. Thus in CDP (Plate IV. Fig. 25.) C is the fulcrum, therefore a power P, acting at B, will fuftain a double weight W, acting at A, for BC is double the diftance of AC from the fulcrum.

Again it is evident, in the prefent cafe, that the whole weight is fuftained by the cord EDP, and whatever fuftains half the cord, fuftains alfo half the weight; but one half is fuftained by the fixed hook E, confequently the power at P has only the other half to fuftain, or in other words, any given power at P will keep in equilibrio a double weight at W.

Charles. Is the velocity of P double that of W?

Father. Undoubtedly; if you compare the fpace paffed through by

the hand at P with that paffed by W, you will find that the former is juft double of the latter, and therefore the *momenta* of the power and weight, as in the lever, are equal.

Charles. I think I fee the reafon of this, for if the weight be raifed an inch, or a foot, both fides of the cord muft alfo be raifed an inch, or foot, but this cannot happen without that part of the cord at P paffing through two inches, or two feet of fpace.

Father. You will now eafily infer from what has been already fhewn of the fingle *moveable* pulley, that in a fyftem of pulleys, the power gained muft be eftimated, by doubling the number of pulleys in the lower or moveable block. So that when the fixed block X (Plate IV.

Fig. 26.) contains two pulleys which only turn on their axes, and the lower bloek *y* contains alfo two pulleys, which not only turn on their axes, but alfo *rife* with the weight, the advantage is as four; that is, a fingle pound at P will fuftain four at W.

Charles. In the prefent inftance alfo I perceive, that by raifing W an inch, there are four ropes fhortened each an inch, and therefore the hand muft have paffed through four inches of fpace in raifing the weight a fingle inch; which eftablifhes the maxim, that what is gained in power is loft in fpace. But, papa, you have only talked of the power balancing or fuftaining the weight, fomething more muft, I fuppofe, be added to raife it.

Father. There muſt; conſiderable allowance muſt likewiſe be made for the friction of the cords, and of the pivots, or axes, on which the pulleys turn. In the mechanical powers, in general, one-third of power muſt be added for the loſs ſuſtained by friction, and for the imperfect manner in which machines are commonly conſtructed. Thus, if by *theory* you gain a power of 600; in *practice*, you muſt reckon only upon 400. In thoſe pulleys which we have been deſcribing, writers have taken notice of three things, which take much from the general advantage and convenience of pulleys as a mechanical power. The *firſt* is, that the diameters of the axes, bear a great proportion to their own diameters. The *ſecond* is, that

in working they are apt to rub againſt one another, or againſt the ſide of the block. And the *third* diſadvantage, is the ſtiffneſs of the rope that goes over and under them.

The two firſt objections have been, in a great degree, removed by the concentric pulley, invented by Mr. James White: B (Plate IV. Fig. 27.) is a ſolid block of braſs, in which grooves are cut, in the proportion of 1, 3, 5, 7, 9, &c. and A is another block of the ſame kind, whoſe grooves are in the proportion of 2, 4, 6, 8, 10, &c. and round theſe grooves a cord is paſſed, by which means they anſwer the purpoſe of ſo many diſtinct pulleys, every point of which moving with the velocity of the ſtring in contact with it, the whole friction is removed to the two centers of mo-

tion of the blocks A and B; befides it is of no fmall advantage, that the pulleys being all of one piece, there is no rubbing one againft the others.

Emma. Do you calculate the power gained by this pulley, in the fame method as with the common pulleys?

Father. Yes, for pulleys of every kind the rule is general, the advantage gained is found by doubling the number of the pulleys in the lower block: in that before you there are fix grooves, which anfwer to as many diftinct pulleys, and confequently the power gained is twelve, or one pound at P will balance twelve pounds at W.

CONVERSATION XIX.

Of the inclined Plane.

FATHER, We may now defcribe the inclined plane, which is the fourth mechanical power.

Charles. You will not be able, I think, to reduce this alfo to the principle of the lever.

Father. No, it is a diftinct principle, and fome writers on thefe fubjects reduce at once the fix mechanical powers to two, viz. the lever and inclined plane.

Emma. How do you eſtimate the advantage gained by this mechanical power?

Father. The method is very eaſy, for juſt as much as the length of the plane exceeds its perpendicular height, ſo much is the advantage gained. Suppoſe AB (Plate IV. Fig. 28.) is a plane ſtanding on the table, and CD another plane inclined to it; if the length CD be three times greater than the perpendicular height; then the cylinder E will be ſupported upon the plane CD, by a weight equal to the third part of its own weight.

Emma. Could I then draw up a weight on ſuch a plane with a third part of the ſtrength that I muſt exert in lifting it up at the end?

Father. Certainly you might; allowance however muſt be made for overcoming the friction; but then you perceive, as in the other mechanical powers, that you will have three times the ſpace to paſs over, or that as you gain power you will loſe time.

Charles. Now I underſtand the reaſon why ſometimes there are two or three ſtrong planks laid from the ſtreet to the ground-floor warehouſes, making therewith an inclined plane, on which heavy packages are raiſed or lowered.

Father. The inclined plane is chiefly uſed for raiſing heavy weights to ſmall heights, for in warehouſes ſituated in the upper part of buildings, cranes and pulleys are better adapted for the purpoſe.

Charles. I have ſometimes, papa, amuſed myſelf by obſerving the difference of time which one marble has taken to roll down a ſmooth board, and another which has fallen by its own gravity without any ſupport.

Father. And if it were a long plank, and you took care to let both marbles drop from the hand at the ſame inſtant, I dare ſay you found the difference very evident.

Charles. I did, and now you have enabled me to account for it very ſatisfactorily, by ſhewing me that as much more time is ſpent in raiſing a body along an inclined plane, than in lifting it up at the end, as that plane is longer than its perpendicular height. For I take it

for granted that the rule holds in the defcent as well as in the afcent.

Father. If you have any doubt remaining, a few words will make every thing clear. Suppofe your marbles placed on a plane, perfectly horizontal, as on this table, they will remain at reft wherever they are placed: now if you elevated the plane in fuch a manner that its height fhould be equal to half the length of the plane, it is evident from what has beeen fhewn before, that the marbles would require a force equal to half their weight to fuftain them in any particular pofition: fuppofe then the plane perpendicular to the table, the marbles will defcend with their whole weight, for now the plane contributes in no refpect to fupport them, confequently

they would require a power equal to their whole weight to keep them from defcending.

Charles. And the fwiftnefs with which a body falls is to be eftimated by the force with which it is acted upon?

Father. Certainly, for you are now fufficiently acquainted with philofophy to know that the effect muft be eftimated from the caufe. Suppofe an inclined plane is thirty-two feet long, and its perpendicular height is fixteen feet, what time will a marble take in falling down the plane, and alfo in defcending from the top to the earth by the force of gravity?

Charles. By the attraction of gravitation, a body falls fixteen feet in a fecond (See p. 61.) therefore the

marble will be one second in falling perpendicularly to the ground; and as the length of the plane is double its height, the marble must take two seconds to roll down it.

Father. I will try you with another example. If there be a plane 64 feet perpendicular height, and 3 times 64, or 192 feet long, tell me what time a marble will take in falling to the earth by the attraction of gravity, and how long it will be in descending down the plane.

Charles. By the attraction of gravity it will fall in two seconds; because, by multiplying the sixteen feet which it falls in the first second, by the square of two seconds (the time) or four; I get sixty-four the height of the plane. But the plane being three times as long as it is

perpendicularly high, it muſt be three times as many ſeconds in rolling down the plane, as it was in deſcending freely by the force of gravity, that is ſix ſeconds.

Emma. Pray, papa, what common inſtruments are to be referred to this mechanical power, in the ſame way, as ſciſſars, pincers, &c. are referred to the lever?

Father. Chiſels, hatchets, and whatever other ſharp inſtruments which are chamfered, or ſloped down to an edge on one ſide only, may be referred to the principle of the inclined plane.

CONVERSATION XX.

Of the Wedge.

FATHER. The next mechanical power is the *wedge*, which is made up of the two inclined planes DEF and CEF (Plate IV. Fig. 29.) joined together at their bafes *e* E F G: D C is the whole thicknefs of the wedge at its back A B C D, where the power is applied, and D F and C F are the length of its fides; now there will be an equilibrium between the power impelling the wedge downward, and the refiftance of the wood, or other fubftance acting againft its

ſides, when the thickneſs DC of the wedge is to the length of the two ſides, or, which is the ſame thing, when half the thickneſs DE of the wedge at its back is to the length of DF one of its ſides, as the power is to the reſiſtance.

Charles. This is the principle of the inclined plane.

Father. It is, and notwithſtanding all the diſputes which the methods of calculating the advantage gained by the wedge have occaſioned, I ſee no reaſon to depart from the opinion of thoſe who conſider the wedge as a double inclined plane.

Emma. I have ſeen people cleaving wood with wedges, but they ſeem to have no effect, unleſs great force and great velocity are alſo uſed.

Father. No, the power of the attraction of cohesion, by which the parts of wood stick together is so great, as to require a considerable *momentum* to separate them. Did you observe nothing else in the operation worthy of your attention?

Charles. Yes, I also took notice that the wood generally split a little below the place to which the wedge reached.

Father. This happens in cleaving most kinds of wood, and then the advantage gained by this mechanical power, must be in proportion as the length of the sides of the cleft in the wood is greater than the length of the whole back of the wedge. There are other varieties in the action of the wedge, but at pre-

ſent, it is not neceſſary to refer to them.

Emma. Since you ſaid that all inſtruments which ſloped off to an edge on one ſide only, were to be explained by the principle of the inclined plane; ſo, I ſuppoſe, that thoſe which decline to an edge on both ſides, muſt be referred to the principle of the wedge.

Father. They muſt, which is the caſe with many chiſſels, and almoſt all ſorts of axes, &c.

Charles. Is the wedge much uſed as a mechanical power?

Father. It is of great importance in a vaſt variety of caſes, in which the other mechanical powers are of no avail; and this ariſes from the momentum of the blow, which is

greater, beyond comparifon, than the application of any dead weight or preffure, fuch as is employed in the other mechanical powers. Hence it is ufed in fplitting wood, rocks, &c. and even the largeft fhip may be raifed to a fmall height by driving a wedge below it. It is alfo ufed for raifing up the beam of a houfe, when the floor gives way, by reafon of too great a burden being laid upon it. It is ufual alfo in fepa-rating large mill-ftones from the filiceous fand-rocks in fome parts of Derbyfhire to bore horizontal holes under them in a circle, and fill thefe with pegs or wedges made of dry wood, which gradually fwell by the moifture of the earth, and in a day or two lift

up the mill-ſtone without breaking it; to this practice Dr. Darwin alludes,

Climb the rude ſteeps, the granite-cliffs ſurround,
Pierce with ſteel points, with wooden *wedges* wound.

BOTANIC GARDEN.

CONVERSATION XXI.

Of the Screw.

FATHER. Let us now examine the properties of the fixth and laft mechanical power, the *fcrew;* which, however, cannot be called a fimple mechanical power, fince it is never ufed without the affiftance of a lever or winch; by which it becomes a compound engine, of great power in preffing bodies together, or in raifing great weights. AB (Plate IV. Fig. 30.) is the reprefentation of one, together with the lever DF.

Emma. You faid juft now, papa,

that all the mechanical powers were reducible either to the lever or inclined plane, how can the ſcrew be referred to either?

Father. The ſcrew is compoſed of two parts, one of which AB is called the ſcrew, and conſiſts of a ſpiral protuberance, called the *thread*, which may be ſuppoſed to be wrapt round a cylinder; the other part C-D, called the *nut*, is perforated to the dimenſions of the cylinder; and in the internal cavity is alſo a ſpiral groove adapted to receive the thread. Now if you cut a ſlip of writing-paper in the form of an inclined plane *abc*, (Fig. 30.) and then wrap it round a cylinder of wood, you will find that it makes a ſpiral anſwering to the ſpiral part of the ſcrew; moreover, if you conſider the aſcent

of the ſcrew, it will be evident that it is preciſely the aſcent of an inclined plane.

Charles. By what means do you calculate the advantage gained by the ſcrew?

Father. There are, at firſt ſight, evidently two things to be taken into conſideration; the firſt is the diſtance between the threads of the ſcrew;—and the ſecond is the length of the lever.

Charles. Now I comprehend pretty clearly how it is an inclined plane, and that its aſcent is more or leſs eaſy as the threads of the ſpiral are nearer or farther diſtant from each other.

Father. Well then, let me examine by a queſtion, whether your conceptions be accurate; ſuppoſe

two ſcrews, the circumferences of whoſe cylinders are equal to one another; but in one, the diſtance of the threads to be an inch apart; and that of the threads of the other only one-third of an inch; what will be the difference of the advantage gained by one of the ſcrews over the other?

Charles. The one whoſe threads are three times nearer than thoſe of the other, muſt, I ſhould think, give three times the moſt advantage.

Father. Give me the reaſon for what you aſſert.

Charles. Becauſe from the principle of the inclined plane, I learnt that if the *height* of two planes were the ſame, but the length of

one, twice, thrice, or four times greater than that of the other, the mechanical advantage gained by the longer plane would be two, three, or four times more than that gained by the ſhorter. Now, in the preſent caſe, the height gained in both *ſcrews* is the ſame, one inch, but the ſpace paſſed in that, three of whoſe threads go to an inch, muſt be three times as great as the ſpace paſſed in the other; therefore, as ſpace is paſſed, or time loſt, juſt in proportion to the advantage gained, I infer that three times more advantage is gained by the ſcrew, the threads of which are one-third of an inch apart, than by that whoſe threads are an inch apart.

Father. Your inference is juſt, and naturally follows from an accurate

knowledge of the principle of the inclined plane. But we have ſaid nothing about the lever.

Charles. This ſeemed hardly neceſſary, it being ſo obvious to any one who will think a moment, that power is gained by that, as in levers of the firſt kind, according to the length F D from the nut.

Father. Let us now calculate the advantage gained by a ſcrew, the threads of which are half an inch diſtance from one another, and the lever 7 feet long.

Charles. I think you once told me, that if the radius of a circle was given, in order to find the circumference, I muſt multiply that radius by 6.

Father. I did, for though that is not quite enough, yet it will anſwer

all common purpoſes, till you are a little more expert in the uſe of decimals.

Charles. Well, then, the circumference of the circle made by the revolution of the lever will be 7 feet, multiplied by 6, which is 42 feet, or 504 inches; but, during this revolution, the ſcrew is raiſed only half an inch, therefore the ſpace paſſed by the moving power, will be 1008 times greater than that gone through by the weight, conſequently the advantage gained is 1008, or one pound applied to the lever will balace 1008 pounds acting againſt the ſcrew.

Father. You perceive that it follows as a corollary from what you have been ſaying, that there are two methods by which you may increaſe

the mechanical advantage of the ſcrew.

Charles. I do;—it may be done either by taking a longer lever, or by diminiſhing the diſtance of the threads of the ſcrew.

Father. Tell me the reſult then, ſuppoſing the threads of the ſcrew ſo fine as to ſtand at the diſtance of but one quarter of an inch aſunder; and that the length of the lever were 8 feet inſtead of 7.

Charles. The circumference of the circle made by the lever will be 8 multiplied by 6, equal to 48 feet or 576 inches, or 2304 quarter inches, and as the elevation of the ſcrew is but one quarter of an inch, the ſpace paſſed by the power, will, therefore, be 2304 times greater than that paſſed by the weight

which is the advantage gained in this inſtance.

Father. A child then capable of moving the lever ſufficiently to overcome the friction, with the addition of a power equal to one pound, will be able to raiſe 2304 pounds, or ſomething more than 20 hundred weight and a half. The ſtrength of a powerful man would be able to do 20 or 30 times as much more.

Charles. But I have ſeen at Mr. W——'s paper-mills, to which I once went, ſix or eight men uſe all their ſtrength in turning a ſcrew, in order to preſs out the water of the newly made paper. The power applied in that caſe muſt have been very great indeed.

Father. It was, but I dare ſay that you are aware that it cannot be

eſtimated, by multiplying the power of one man by the number of men employed.

Charles. That is becauſe the men ſtanding by the ſide of one another, the lever is ſhorter to every man the nearer he ſtands to the ſcrew, conſequently, though he may exert the ſame ſtrength, yet it is not ſo effectual in moving the machine, as the exertion of him who ſtands nearer to the extremity of the lever.

Father. The true method therefore of calculating the power of this machine, aided by the ſtrength of theſe men, would be to eſtimate accurately the power of each man according to his poſition, and then adding all theſe ſeparate advantages together for the total power gained.

Emma. A machine of this kind, is, I believe, ufed by book-binders, to prefs the leaves of the books together before they are ftitched?

Father. Yes, it is found in every book-binder's work-fhop, and is particularly ufeful where perfons are defirous of having fmall books reduced to a ftill fmaller fize for the pocket. It is alfo the principal machine ufed for coining money;—for taking off copper-plate prints; and for printing in general.

Charles. I remember Dr. Darwin's defcription of coining,

With iron lips his rapid rollers feize
The length'ning bars, in thin expanfion
 fqueeze;
Defcending *fcrews* with pond'rous fly-wheels
 wound
The tawny plates, the new medallions round;

Hard dies of Steel the cupreous circles cramp,
And with quick fall his maſſy hammers ſtamp.
The Harp, the Lily, and the Lion join,
And George, and Britain guard the ſterling coin.

BOTANIC GARDEN.

Father. Theſe lines are deſcriptive of Mr. Boulton's magnificent apparatus for coining, the whole machinery is worked by an improved ſteam-engine, which rolls the copper for half-pence; works the ſcrew-preſſes for cutting out the circular pieces of copper; and coins both the faces and edges of the money at the ſame time: and ſince the circulation of the new half-pence, we are all acquainted with the ſuperior excellence of the workmanſhip. By this machinery four boys of ten or twelve years old, are capable of

ſtriking 30,000 guineas in an hour, and the machine itſelf keeps an unerring account of the pieces ſtruck.

Emma. And I have ſeen the cyder-preſs in Kent, which conſiſts of the ſame kind of machine.

Father. It would, my dear, be an almoſt endleſs taſk, were we to attempt to enumerate all the purpoſes to which the ſcrew is applied in the mechanical arts of life; it will, perhaps, be ſufficient to tell you, that wherever great preſſure is required, there the power of the ſcrew, is uniformly employed.

END OF THE FIRST VOLUME.

Printed by Bye and Law, St. John's-Square, Clerkenwell.

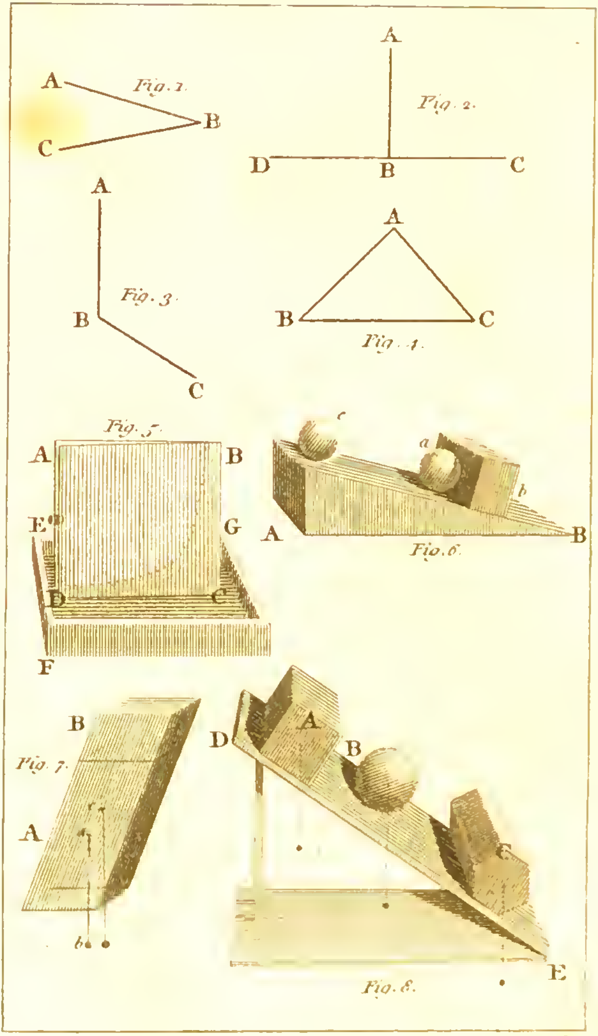
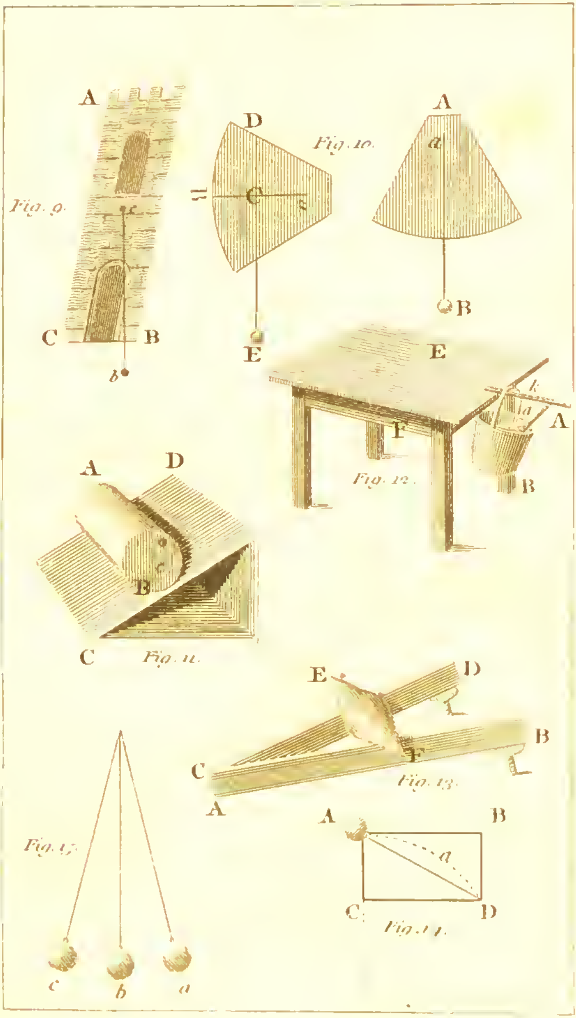


Fig. 1.
A
B
C
Fig. 2.
A
D
B
C
Fig. 3.
A
B
C
Fig. 4.
A
B
C
Fig. 5.
A
B
E
G
D
C
F
Fig. 6.
c
a
b
A
B
Fig. 7.
B
A
b
Fig. 8.
A
B
C
D
E

Lowry sculp.



Lowry sculp

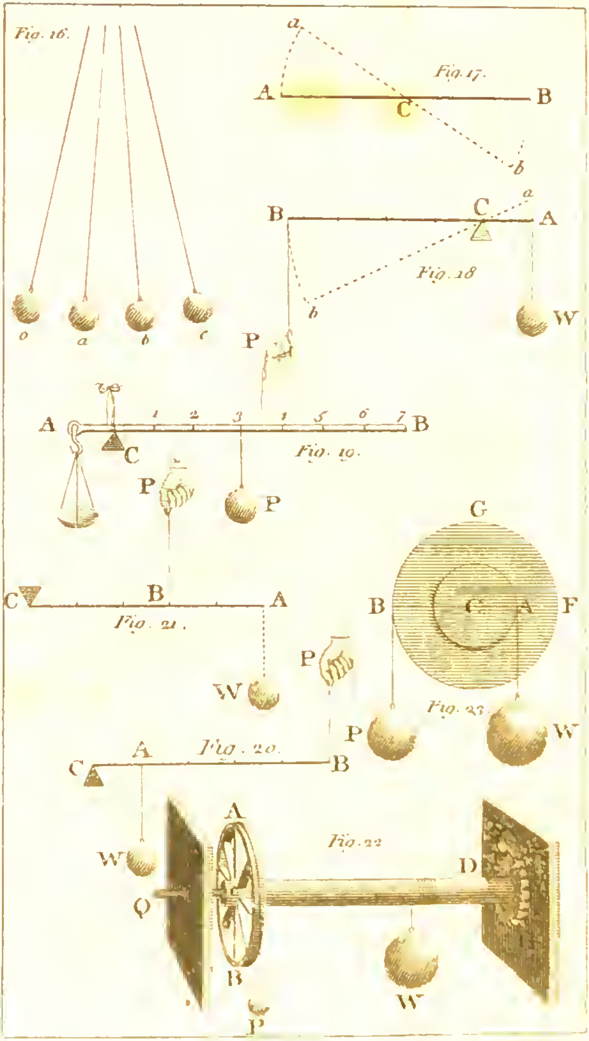


Fig. 16.
o
a
b
c
Fig. 17.
a
A
C
B
b
Fig. 18.
B
C
a
A
b
W
P
Fig. 19.
A
1 2 3 4 5 6 7
B
C
P
P
Fig. 21.
C
B
A
W
Fig. 23.
G
B
C
A
F
P
P
W
Fig. 20.
C
A
B
W
Fig. 22.
A
D
Q
B
W
P

Fig. 24

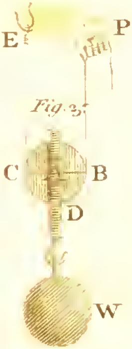


Fig. 25

Fig. 26

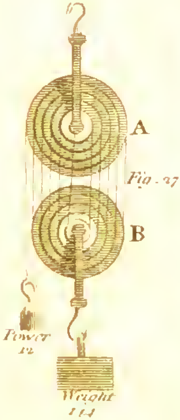


Fig. 27

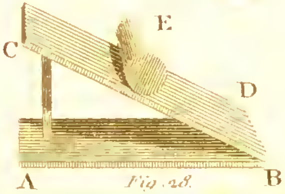


Fig. 28

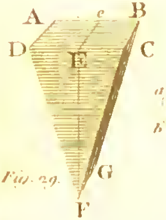


Fig. 29

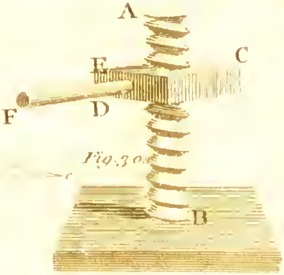


Fig. 30